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Research Article

Evaluation of Common Bean (*Phaseolus vulgaris* L.) Genotypes for Adaptation to Low Phosphorus

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Common bean production in Tanzania is constrained by soil phosphorus which is mainly due to inherently low phosphorus content, soil erosion, and fixation by oxides in acidic soils. A study was conducted to evaluate bean genotypes in a screen house pot experiment for their ability to thrive and produce on low phosphorus soil. Assessment of shoot biomass, root biomass, shoot P concentration, P uptake, and yield components was done using three phosphorus levels and seven bean genotypes. Phosphorus levels, namely, control (P0), medium P (40 mg P/kg), and high P (160 mg P/kg), were the main plot factor, while the genotypes were the subplot in split plot structure, arranged in a completely randomized design. Shoot and root biomass as well as P uptake increased significantly with increase in phosphorus levels. There was varying response of genotypes in performance in terms of shoot biomass P uptake, and yield in a treatment without P addition. Genotypes *MILENIO, BAT477*, and *A785* were outstanding in terms of root and shoot biomass, P uptake and grain yield under low P treatment. Therefore, those genotypes can be recommended for use in low-phosphorus environment as well as breeding materials.

1. Introduction

Bean production in Tanzania is undertaken by small-scale farmers for household consumption, surplus of which is traded for cash. Bean yields are low due to diseases and low soil fertility, particularly phosphorus deficiency [1, 2]. The declining soil phosphorus in Tanzania is due to continued nutrient mining without replenishment. It is estimated that beans remove 12.5 kg P/ha which is higher than additions in terms of phosphorus fertilisation by resource-poor farmers [3]. It has been reported that soils in major bean growing areas of Tanzania have very low concentrations of extractable phosphorus ranging from 1.6 to 3.1 mg P/kg soil [4]. The use of fertilizer is very low as it is at an average rate of 1.9 kg P/ha of cultivated land [5] due to high costs of fertilizers and transport [6], unpredictable rainfall, inadequate supply, untimely availability of fertilizer, and lack of credit [7]. However, phosphorus deficiency can be overcome by corrective soil fertility amendment strategies such as application of phosphatic fertilizers and liming of acidic soils.

It is difficult for farmers in developing countries, Tanzania in particular, to undertake soil fertility amendments. Bean production is constrained by low phosphorus; the need for bean varieties are capable of acquiring phosphorus from limiting soil environments is of obvious importance. The ability of common bean to acquire phosphorus from phosphorus-limiting environments has been reported to vary among genotypes and this ability is heritable [8, 9]. Nevertheless, increased root growth and modified architecture [10], altering the root growth angle [11] and production of adventitious roots [12], have all been reported to be the root traits that are necessary for adaptation of bean to phosphorus limiting environment. Others include enhanced expression of P transporters [13] and increased production and secretion of phosphatases [14]. Although much has been done in breeding beans for resistance to biotic constraints such as diseases and other pests, less has been done in the abiotic stress area. For instance, twenty improved bean varieties that have been released in Tanzania since 1959, and none has been dedicated for adaptation to phosphorus-limiting environments [1]. Therefore, the objectives of this

Table 1: Common bean genotypes used in the experiment.

Sn	Genotypes	Origin (country)	Seed coat color	Seed size
1	A 785	Colombia	Black	Small
2	DOR 714	Colombia	Black	Small
3	MILENIO	Honduras	Red	Small
4	BAT 477	Colombia	Cream/Beige	Small
5	AFR 708	Congo	Black	Small
6	VEF 88 (40)	Congo	Deep Red	Small
7	ANT 22	Colombia	Red	Large

Table 2: Selected properties of the soil used for the experiment.

Soil character	Unit	Value	Rating/remarks
pH	—	5.4	Low
Organic carbon	%	1.0	Low
Total nitrogen	%	0.1	Low
Bray-1-P	mg/kg	7.3	Low
CEC	me/100 g soil	15.8	Medium
Exchangeable Ca	me/100 g soil	2.2	Low
Exchangeable Mg	me/100 g soil	2.2	Medium
Exchangeable K	me/100 g soil	1.1	Low
Exchangeable Na	me/100 g soil	1.2	Low

study were (i) to determine the effect of phosphorus levels on vegetative plant growth; (ii) to evaluate bean genotypes variability in terms of phosphorus uptake under limiting soil phosphorus, and (iii) to determine bean yield at varying phosphorus levels.

2. Materials and Methods

A pot experiment was conducted in a screen house at Sokoine University of Agriculture (6°45′ S and 37°40′ E), Morogoro, Tanzania. The soil for the experiment was collected from Magadu area of the university farm and has been classified as isohyperthermic, very fine, *kaolinitic Kanhaplic Haplustult* [15]. A subsample of the sieved soil was taken for determination of chemical characteristics. Soil pH was determined in 1 : 2.5 soil : water suspension (pHw). Exchangeable calcium (Ca) and magnesium (Mg) were determined by atomic absorption spectrophotometry, whereas K and Na were extracted using ammonium acetate and analysed by flame photometry (NH_4OAc 1.0 M, pH 7.0). Cation exchange capacity (CEC_{pH7}) was determined by ammonium acetate saturation method at pH 7.0. Available P was extracted using the Bray 1 method and determined by ascorbic acid-molybdate blue colour method. Organic carbon (OC) was determined by Walkley-Black wet combustion method, while total *N* was determined by Kjeldahl method, both as described by Tan [16].

Phosphorus was applied to the soil in the form of triple superphosphate (TSP) at the rate of 0, 40, and 160 mg P/kg soil (designated as P0, P40 and P160 resp.) in a split plot structure arranged in a completely randomized design with P levels as main factor and common bean genotypes as subfactor. The 40 mg P/kg soil was chosen to cater for situations where P is applied at low rate by growers, whereas the 160 mg P/kg soil has been reported to be an adequate quantity for the Magadu soil in an earlier pilot study using TSP [15]. Four kilograms of soil were filled in 4-litre plastic pots; the total number of pots used was 63. Basal application of nutrients per kg soil was as follows: 40 mg nitrogen (N) as $((NH_4)2SO_4)$, 10 mg K (as KCl) 10 mg Zn (as $ZnSO_4$), and 1 mg molybdenum (as ammonium molybdate). Seven common bean genotypes from CIAT were used (Table 1). Four seeds/pot were sown, later thinned to two seedlings at 10 days after sowing (DAS). At the start of flowering, corresponding to R5 growth stage [17], one plant was harvested from each pot for biomass measurement and tissue analysis whereas the remaining plant was left to grow up to maturity. Shoots were cut just above the soil level, oven dried at 70°C for 48 hours, weighed to determine shoot biomass and ground for subsequent tissue analysis. Roots were separated from soil by soaking the intact root system into water and gently washing away the soil particles. The roots were initially sun-dried and then put in an oven at 60°C for 60 hours and weighed to determine root biomass. Shoot P concentration was determined following Ammonium Molybdate blue method as described by Murphy and Riley [18].

3. Data Analysis

Data were analysed using GENSTAT v.14. software (VNS International Hempstead, UK) where analysis of variance and correlation among the variable were performed. Means were separated using least significant difference (LSD) test at 95% significance level.

4. Results

Soil analysis results were summarised in Table 2. The soil was characterised by low pH, low available phosphorus, and

Table 3: Analysis of variance for variables measured from seven common bean genotypes.

Variable	P levels	Genotypes	P × G
Root biomass (g/plant)	***	***	***
Shoot biomass (g/plant)	**	***	***
Shoot P concentration (%)	**	**	**
P uptake (mg P/plant)	***	***	***
Number of pods/plant	***	***	***
Number of seeds/pod	NS	***	**
Grain yield (Kg/ha)	**	***	***
100-seed weight (g)	NS	***	NS

*,**,*** Significant F values at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively; NS: not significant.

Table 4: Effect of P levels on root biomass, shoot biomass, shoot P concentration, and P uptake of seven genotypes.

P levels	Root biomass (g/plant)	Shoot biomass (g/plant)	Shoot P concentration (%)	P uptake (mg P/plant)
P0	1.40 c	3.42 c	0.196 b	6.82 c
P40	1.95 b	4.33 b	0.184 b	7.68 b
P160	2.36 a	5.66 a	0.224 a	12.69 a
Mean	1.903	4.47	0.201	9.07
CV (%)	11.2	8.69	11.09	6.36
LSD	0.29	0.31	0.013	1.42

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).

low nitrogen [19]. This kind of soil was appropriate for the testing of bean genotypes for tolerance to low soil fertility especially phosphorus.

Analysis of variance indicated that there was highly significant effect of phosphorus levels on all tested variables except the number of seeds per pod. Likewise, the effect of genotypes and phosphorus by genotypes interaction was highly significant for all but one variable tested (Table 3)

The effects of phosphorus levels on the root biomass, shoot biomass, percentage shoot P concentration and P uptake were highly significant ($P < 0.05$) (Table 4). Root biomass increased significantly with increase in phosphorus levels, being lower and higher at low and high phosphorus levels, respectively. Shoot biomass increased significantly as phosphorus levels increased. Percentage shoot P concentration was not significantly different between P0 and P40 but was high in P160 treatment. As for phosphorus uptake, there was also significant increase as phosphorus levels increased. High phosphorus level (P160) treatment resulted into higher levels across all the parameters tested.

The effects of genotypes on root and shoot biomass, percentage shoot P concentration, and P uptake were highly significant ($P < 0.05$) (Table 5). The root biomass was highly variable among genotypes ranging from 1.36 g/plant for ANT22 to 2.15 g/plant for A785. Likewise, shoot biomass varied significantly ($P < 0.05$) among the genotypes, ranging from 3.23 g/plant for ANT22 to 5.2 g/plant for A785. All other genotypes did not differ statistically with respect to the shoot biomass.

Shoot P concentration ranged from 0.175% for genotype VEF88(40) to 0.222% for ANT22. P uptake which is the product of shoot biomass and shoot P concentration varied significantly among the genotypes, ranging from 6.82 mg p/plant for ANT22 to 11.015 mg p/plant for A785. Genotype A785, featured prominently for all variables except shoot P concentration, while genotype ANT22 scored least for all variables except percentage P concentration.

Generally, root biomass increased with increase in phosphorus levels for all genotypes. However, this parameter increased for genotype VEF 88 (40), and BAT477 increased up to P40 treatment and declined at high P treatment (P160). Unlike in other genotypes, there was a decline in root biomass at P40 treatment for genotype ANT22 and an increase at P160 (Figure 1). At high P treatment, root biomass increased for genotypes A785, MILENIO, and DOR714 relative to other genotypes.

Shoot biomass generally increased significantly when phosphorus was increased from P0 to P160 for all genotypes. However, there was a decrease in shoot biomass at P40 for genotype ANT 22, which still increased at P160 (Figure 2). The response to high phosphorus level in terms of shoot biomass for the genotypes A785, AFR 708, and DOR 714 was profound, while there was small change in this aspect at high P level in genotype VEF 88(40). Shoot biomass declined at P40 but increased at P160 for genotype ANT 22.

Generally, there was no significant difference ($P \leq 0.05$) in shoot P concentration between P0 and P40 treatments among genotypes. Genotypes A785, VEF 88(40), and MILENIO did not show any significant change in P concentration at P40 treatment, when compared with the control (P0) (Figure 3). Genotypes BAT 477, AFR 708, and DOR 714 had low shoot P concentration at P40 treatment, whereas genotype ANT 22 had the highest at P40 treatment.

Genotype A785 had the highest P uptake among all genotypes at low P treatment, whereas genotypes BAT 477 and AFR 708 had the lowest (Figure 4). Generally, P uptake did not increase significantly between P0 and P40 among genotypes especially for genotypes VEF 88(40), AFR 708,

Table 5: Variability of bean genotypes with respect to root biomass, shoot biomass, shoot P concentration, and P uptake.

Genotypes	Root biomass (g/plant)	Shoot biomass (g/plant)	Shoot P concentration (%)	P uptake (mg p/plant)
A785	2.15 a	5.2 a	0.195 bc	11.015 a
DOR714	2.14 a	4.62 b	0.218 a	10.21 b
MILENIO	2.07 ab	4.77 b	0.200 ab	9.62 c
BAT477	1.92 bc	4.544 b	0.205 ab	9.12 cd
AFR708	1.84 c	4.48 b	0.193 bc	8.825 d
VEF88(40)	1.86 bc	4.46 b	0.175 c	7.855 e
ANT22	1.36 d	3.23 c	0.222 a	6.82 f
Mean	1.91	4.47	0.20	9.07
CV (%)	11.20	8.69	11.09	6.36
LSD	0.2	0.372	0.021	1.10

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).

Table 6: Effect of P levels on the number of pods/plant, seeds/pod, 100-seed weights and grain yields for seven genotypes.

P Levels	Pod/Plant	Seed/Pod	100 SW (gm)	Yield (kg/ha) (×1000)
P0	3.17 c	3.20 b	26.24 a	2.71 c
P40	5.14 b	3.39 ab	26.14 b	4.13 b
P160	7.5 a	3.64 a	22.85 c	5.37 a
Mean	6.32	3.41	25.07	4.75
CV (%)	8.11	16.33	6.59	5.86
LSD	0.204	0.345	1.87	0.772

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).

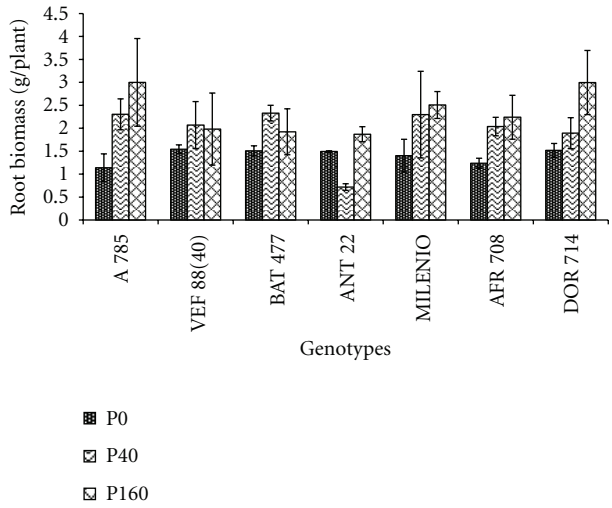

Figure 1: Phosphorus and genotypes interaction effect on root biomass at 30 DAS.

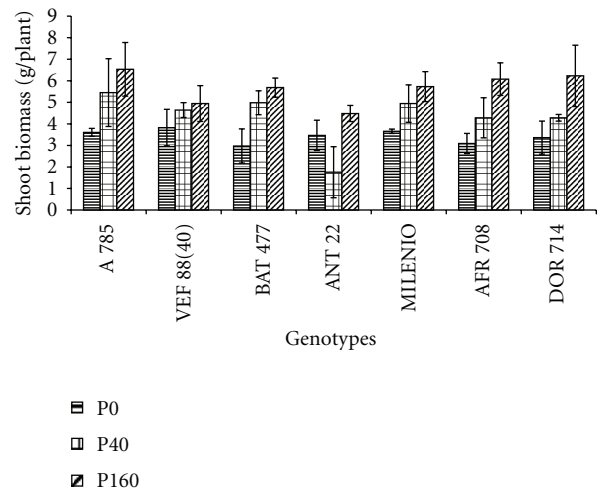

Figure 2: Phosphorus and genotypes interaction effect on shoot biomass at 30 DAS.

and DOR 714. At P160, there was high response among genotypes in terms of P uptake, particularly for genotypes A785, BAT 477, DOR 714, AFR 708, and MILENIO. Genotype ANT 22 had P uptake declining at P40, unlike in other genotypes whose P uptake increased consistently when P levels increased.

Generally, phosphorus treatment had significant ($P < 0.05$) effects on the number of pods/plant, seeds/pod, 100-seed weight and grain yields. With exception of 100 seed weights, which decreased as P levels increased, all variables increased with increase in P levels (Table 6).

There was significant ($P \leq 0.05$) variability among genotypes with respect to number of pods/plant, seeds/pod, grain yields and 100-seed weights. Genotype BAT 477 had the highest number of pods/plant, whereas genotype ANT 22 had the lowest (Table 7). Genotype MILLENIO exhibited higher number of seeds/pod, while ANT 22 had the lowest. Hundreds-seed weight for genotype ANT 22 was the highest when compared with other genotypes. This genotype is large seeded, suggesting why it featured profoundly in this parameter. Genotype BAT 477 had-higher grain yield, while genotype ANT 22 had the lowest-grain yield. Genotypes

Table 7: Effect of bean genotypes on number of pods/plant, seeds/pod, 100-seed weight, and grain yields.

Genotype	Pod/plant	Seed/pod	100-seed weight (gm)	Yield (kg/ha) (×1000)
BAT 477	5.83 a	4.14 ab	24.01 b	5.14 a
MILLENIO	5.39 bc	4.18 a	19.74 c	4.50 b
DOR714	4.67 d	3.64 bc	22.94 b	3.83 d
VEF 88 (40)	5.33 c	3.08 d	22.82 b	3.89 d
AFR 708	5.67 abc	4.04 ab	18.46 c	3.93 d
A785	5.77 abc	3.27 cd	23.25 b	4.21 c
ANT 22	4.23 e	1.54 e	44.32 a	2.99 e
Mean	5.27	3.41	25.07	4.07
CV (%)	8.11	16.33	6.59	5.86
LSD	0.41	0.53	1.58	0.23

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).

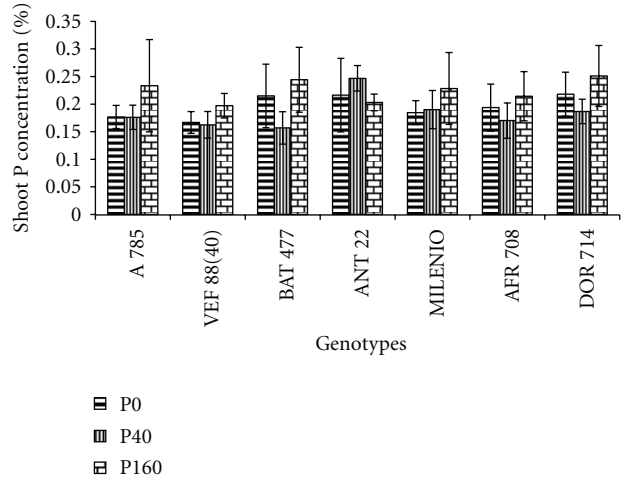

Figure 3: Phosphorus and genotypes interaction effect on shoot P concentration at 30 DAS.

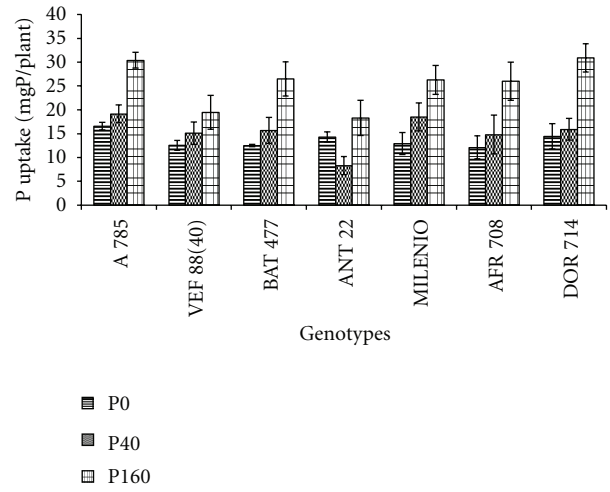

Figure 4: Phosphorus and genotypes interaction effect on P uptake at 30 DAS.

DOR 714, VEF 88(40), and AFR 708 were not statistically different with respect to grain yield. BAT 477 featured prominently in terms of high values in number of pods/plant, seeds/pod, and grain yields whereas genotype ANT 22 performed poorly across the test parameters except in 100-seed weight.

The general trend was that the number of pods/plant for all genotypes increased as P increased (Figure 5). The response to high P treatment was high for genotypes BAT 477, MILENIO, VEF 88(40), AFR 708, and A 785. Genotypes DOR 714 and ANT 22 did not show significant increase in the number of pods/plant at high P treatment. Although genotype BAT 477 showed high response to high P level, the number of pods/plant at P40 did not differ statistically ($P \leq 0.05$) from the control treatment.

The number of seeds/pod for genotypes BAT 477, MILENIO, VEF 88(40), AFR 708, and A785 in control P treatment did not differ from those in the high P treatment (Figure 6). Genotype ANT 22 exhibited an increase in the number of seeds/pod as P increased. The number of seeds/pod for genotype AFR 708, was higher at P40 than at other levels.

The 100-seed weight for most genotypes except BAT 477 was slightly higher at low P level than at high P level (Figure 7). Genotype ANT 22 had significant highly 100-seed weight due to its large seed size.

P levels and genotypes significantly ($P \leq 0.05$) affected grain yield increasing with increase in P levels (Figure 8). Genotypes BAT 477, MILENIO, A 785, and ANT 22 responded significantly with P increase, unlike genotypes DOR 714, VEF 88(40), and AFR 708 which exhibited low response to high P treatment.

The number of pods per plant was positively correlated with grain yield at low P level ($r = 0.855^{**}$) and positively correlated with grain yield at high P level ($r = 0.759^{*}$) (Table 8). At low P, the number of seeds/pod was negatively correlated with 100-seed weight ($r = -0.916^{**}$) indicating that genotypes whose average number of seeds/pod was high, their 100-seed weight was low at deficient P level. At medium P level, grain yield was only correlated to the number of seeds/pod ($r = 0.914^{**}$) (Table 9). At high P treatment, the number of pods per plant was positively correlated with grain yield ($r = 0.759^{*}$), whereas 100 seed weight was negatively correlated with the number of seeds/pot ($r = -0.737^{*}$) (Table 10).

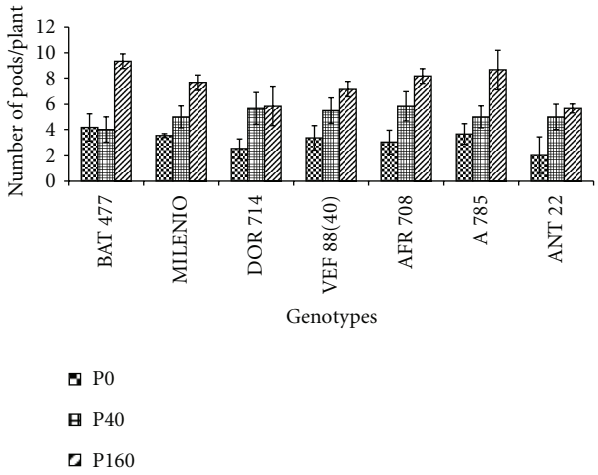

Figure 5: Phosphorus and genotypes interaction effect on number of pods/plant.

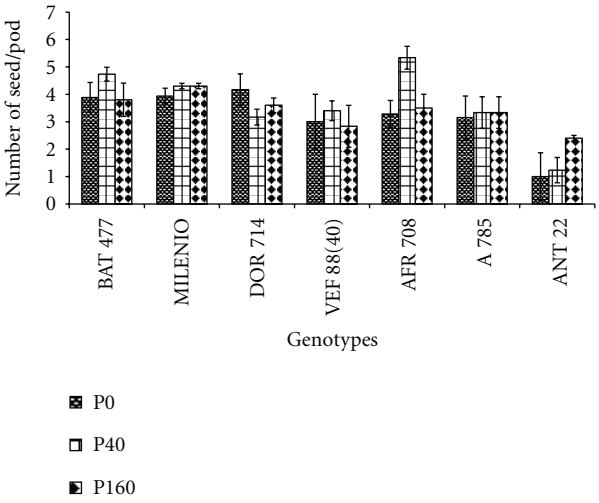

Figure 6: Phosphorus and genotypes interaction effect on number of seed/pod.

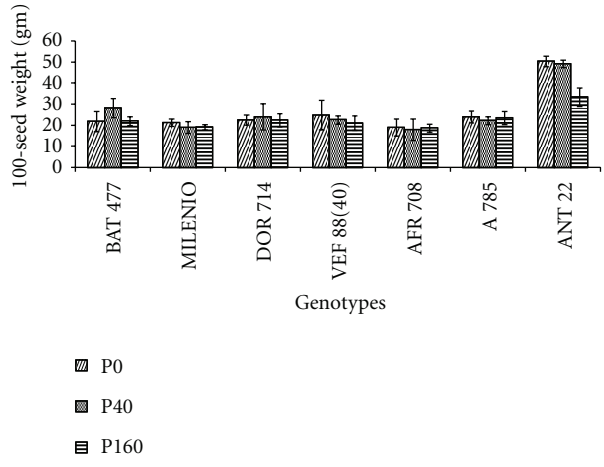

Figure 7: Phosphorus and genotypes interaction effect on 100 seed weight (g).

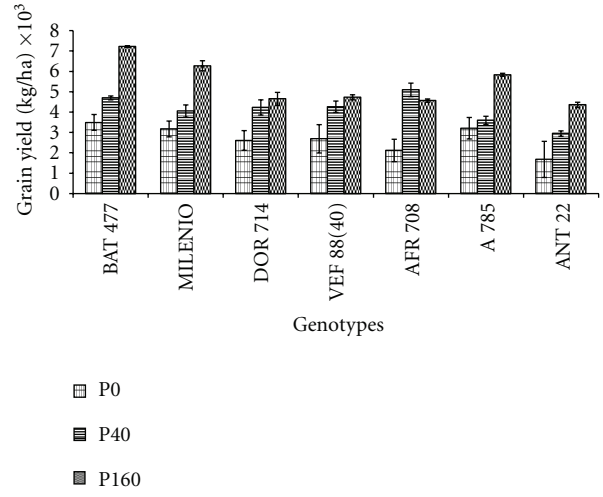

Figure 8: Phosphorus and genotypes interaction effect on grain yield (kg/ha).

5. Discussion

Ultisols [20] were the soils used under this experiment. These are typical soils making up to 2.8% of major soils on which common bean production is undertaken in East Africa [21]. Ultisols are highly weathered soils, characterised by low cation exchange capacity, low exchangeable bases, and low pH. In such soils, available phosphorus becomes limited due to fixation by sesquioxides which occupy much of upper horizons as a result of intensive weathering. However, for increased bean yield, soil fertility amendment strategies including application of organic matter [22], phosphatic fertilizer [23] or rock phosphate [24] may enhance bean yield under similar climatic conditions. Bean production by resource poor farmers without means to ameliorate soil fertility problems, using bean varieties adapted to low phosphorus soils may be important in improving the yields.

Phosphorus is relatively immobile in soil [25, 26]; thus, extensive root system would be an important trait for adapted genotypes to explore large soil volume so that sufficient quantities are taken up. It is for this reason therefore that plants under deficient P conditions, respond by allocating large fraction of their net carbon assimilation to the production of root rather than photosynthetic tissues [27], resulting high root/shoot ratio [28, 29]. In our results, we infer genotypes with high root biomass at low phosphorus to their inherent ability to thrive under limiting P environments. However, this variable may not be used without

Table 8: Simple correlation of grain yield and yield components at P0.

Parameter	Grain yield	Pods/plant	Seed/pod
100-seed wt	−0.699 ns	0.670 ns	−0.916**
Seed/pod	0.801*	0.591 ns	
Pod/plant	0.855**		

*,** Significant F values at $P \leq 0.05$ and $P \leq 0.01$, respectively; ns: not significant.

Table 9: Simple correlation matrix of yield and yield components at $P = 40$ mg P/kg soil.

Parameter	Grain yield	No. of pods/plant	No. of Seeds/pod	100-seed wt.
100 seed wt	−0.710 ns	0.670 ns	−0.310 ns	
Seed/pod	0.914**	−0.021 ns		
Pod/plant	0.142 ns			

*,** Significant F values at $P \leq 0.05$ and $P \leq 0.01$, respectively; ns: not significant.

Table 10: Simple correlation matrix of yield and yield components at $P = 160$ mg P/kg soil.

Parameter	Grain yield (Kg/ha)	Pods/plant	Seeds/pod
100-seed wt	0.327 ns	−0.541 ns	−0.737*
Seed/pod	0.676 ns	0.506 ns	
Pod/plant	0.759*		

* Significant F values at $P \leq 0.05$; ns: not significant.

caution as selection criterion for bean genotypes grown in soil cultures since, due to subterranean nature and fineness of the root system, recovery of the whole root system might have been incomplete.

Results from this study corroborate the hypothesis that common bean differs in their ability to thrive in P-limiting environments [8, 30]. The genotypes with high shoot biomass at low P treatment imply that they possess enhanced mechanism to acquire phosphorus in P-limiting environments, and/or they can utilize absorbed P more efficiently to produce relatively large biomass. At low nutrient availability, plants partition large fraction of resources to the root system and as a result, leaf growth and expansion become restricted such that there is a decline in above ground biomass and eventually decline in yield [27]. Therefore, this suggests that P deficiency restricts leaf expansion and consequently, less carbon assimilation resulting into low shoot biomass under low P treatment. Also, at low P, the plants may respond to this situation by diverting large fraction of their net carbon assimilation to the production of heterotrophic rather than photosynthetic tissues, which ultimately results in an increase in root:shoot ratio [28]. Therefore, the genotypes that have high mean shoot biomass at deficient phosphorus level may be termed as efficient, probably because, soil P is somehow sufficient for them or they invest large part of the assimilate to the roots for enhanced soil exploration to support shoot biomass production.

Critical tissue P concentration for common bean below which normal plant growth may not occur is 0.2% [31]. The nonsignificant difference between low and medium P treatments in as far as shoot P concentration is concerned may be due to the following reasons. First is that since shoot biomass increased at P40 treatment for all genotypes, there might have been dilution effect [31], [32] where phosphorus is distributed within a bigger biomass in plants as exhibited in P40 treatment. Second, it is possible that Al and Fe oxides which are typical constituents in acidic soils [26] may fix much of the phosphorus at P40, thus rendering it unavailable for the bean plants. However, tissue P concentration increased with increase in soil P availability, therefore, shoot P concentration was more pronounced at higher P treatment.

Plant P uptake depends not only on P available in the soil but also on plant adaptation and properties such as root architecture [8], possession of adventitious roots [12, 30] and exudation of anions in the rhizosphere [26]. An increase in P uptake with increase in P availability among genotypes is in line with the study by [33] where shoot biomass and P uptake were positively correlated at both low and high P supply for bean genotypes. The differences in P uptake among the genotypes across P treatments show the diversity in efficiency with which bean plants are able to absorb phosphorus from the soils of varying availability. Thus, P uptake is the good indicator with respect to P acquisition as it combines both shoot biomass and shoot P content. Therefore, bean genotypes, which perform better or poorly in either of the two parameters, (i.e., shoot biomass or shoot P concentration) are easily identified and hence may not be favored in selection.

The increase in the number of pods per plant with increase in P levels conforms to the results by Yan et al. [8]. However, the lack of significant ($P \leq 0.05$) phosphorus x genotype interaction in this parameter suggests that perhaps P is not the only requirement for pod formation although P deficiency affects pod formation and filling in legumes as it has been suggested by Marschner [34].

Although the number of seeds per pod is an important yield component, it was not related to the P levels for all bean genotypes, agreeing with the results from a study on faba beans (*Vicia faba* L.) by Bolland et al. [35]. Tariq et al. [36] reported narrow differences between the number of seed per pod in mung bean (*Vigna radiata* L.) at varying phosphorus and potassium levels, suggesting that this parameter is genetically controlled or is controlled by multiple environmental factors such as high temperature. This also may be the case in this study, evidenced by lack of P levels and P × G interaction effect on the number of seeds per pod. To the contrary, Yan et al. [8] reported that number of seeds per pod increased with increase in P levels. In our case, the nonsignificant effects of P levels on the number of seed/pod warrant further investigation.

While Melo et al. [37] reported that seed weight (100-seed weight) is controlled by small number of genes which imply more limited response to environmental influences, Szilagy [38] reported that drought reduced it by 13%. In our study, this trait was negatively affected by increased P level as it was also negatively correlated with the number of seeds per pod. This suggests that P may not be the only factor that influences seed weight. In pot experiments where soil volume tends to be small and can be thoroughly exploited by plant roots, higher P supply might have triggered other nutrient deficiency, especially nitrogen and potassium, leading to less assimilate allocation to the seeds. Thus, the counteractive effects of other environmental variables may be responsible for swathing the expression of seed weight traits in common bean.

Response of bean genotypes to higher P levels indicates that P is pertinent for increased bean productivity. Although grain yield increased with increase in P levels, genotypes differed in the degree of response to higher P levels, suggesting that bean genotypes differ both within and between P treatments. Under low P availability, bean genotypes suffer from reduced photosynthesis rate [29, 39], thus leading to low grain yield, unlike for those at high P levels. In most cases, grain yield is the ultimate goal of the grower; therefore, it is an important criterion in adopting a genotype for low soil fertility situations. Bean genotypes which sustain low P levels may be considered efficient and thus worthy of further investigation for inclusion in crop improvement programs. Therefore, such genotypes as *MILENIO*, *BAT477*, and *A785* may be considered for inclusion in breeding for low fertility tolerance, especially phosphorus deficiency.

6. Conclusions

Soil fertility problems for common bean production can be overcome by growing crop plants which are adapted to low fertility condition in circumstances where other soil amendment strategies are not readily practical. However, this is not possible until these adapted crop genotypes are developed. This study revealed that common bean genotypes differ in production of root and shoot biomass as well as phosphorus uptake. Although some genotypes exhibited an outstanding performance in terms of shoot biomass P uptake and yield, fertility improvement would still be very important if economical bean production is to be undertaken in places with soils of low P concentration as the one used in this study. The soil used in this experiment was deficient in phosphorus and represents typical soils to which common bean is grown in Tanzania. Genotypes *MILENIO*, *BAT477*, and *A785* were outstanding in terms of root and shoot biomass, P uptake, and grain yield under low P treatment. They can therefore be considered for incorporation into breeding program for low soil fertility tolerance. Moreover, these genotypes exhibited a good potential to give higher economic yield when P fertilizers are used.

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