Journal of Energy and Natural Resources
2020; 9(4): 103-110
http://www.sciencepublishinggroup.com/j/jenr
doi: 10.11648/j.jenr.20200904.11
ISSN: 2330-7366 (Print); ISSN: 2330-7404 (Online)

Yield and Growth of Common Bean (*Phaseolus vulgaris* L.) Varieties as Influenced by Lime and Phosphorus Under Acid Soil Toxicity of South Western Ethiopia

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To cite this article:
Tolossa Ameyu, Yechalew Sileshi, Mesfin Hailemariam. Yield and Growth of Common Bean (*Phaseolus vulgaris* L.) Varieties as Influenced by Lime and Phosphorus Under Acid Soil Toxicity of South Western Ethiopia. *Journal of Energy and Natural Resources.* Vol. 9, No. 4, 2020, pp. 103-110. doi: 10.11648/j.jenr.20200904.11

Received: November 23, 2020; **Accepted**: December 4, 2020; **Published**: December 11, 2020

Abstract: Acidic soils limit the productive potential of crops because of low availability of basic cations and excess of hydrogen and aluminium in exchangeable forms. At the study area, soil acidity is a well-known problem limiting crop productivity. Therefore, this study was conducted to identify common bean variety that tolerate acid soil or low pH soil. Fifteen (15) common bean variety were grown in split plot design under four soil amendments (limed alone, phosphorus alone, both lime and phosphorus treated, and no any amendment) with three replications at three locations in Western and South Western Ethiopia. Data on growth and yield were collected and analyzed using SAS version 9.3 software. Treatment means were compared at 5% level of significance using List significant Different. The results revealed that variety X amendments X locations X seasons interactions were significant ($p<0.01$) for both grain yield and plant height. Availability of varietal difference among common bean varieties under both amended and unamended acid soil conditions was observed. The highest grain yield (1.043 t/ha) under control soil conditions obtained from this result is still below the national average (1.59t/ha), but more than the national average under lime and phosphorus treated plots (1.989t/ha), which shows that the selected variety is responded to lime and phosphorus than tolerant to acid soil. SER 119 variety is selected for those farmers who have the capacity to apply lime with phosphorus based on the yield performance at both locations and also this variety is included in the future work of further selection trials. However, further study is required including considering additional genotypes, at least for three or four years to determine the residual effect of phosphorus and lime to reach at a conclusive recommendation.

Keywords: Acid Soil, Common Bean, Lime and Phosphorus

1. Introduction

Common bean (Phaseolus vulagris *L*), is locally known as Boleqe‘ also known as dry bean and haricot bean, is a very important legume crop grown worldwide and it is one of the most important and widely cultivated species of Phaseolus in Ethiopia. Its high protein content (20-25%) supplements diets of small holder farmers whose diet is based on cereals, root and tuber crops and banana; a balanced diet can be obtained if cereals and legumes are consumed in the ratio 2:1 [2]. Common bean is thought to be introduced to Ethiopia by the Portuguese in the 16th century [14]. Nowadays, in addition to its subsistence value, common bean is an important commercial crop contributing significant incomes to the majority of the rural peasants in Sub-Saharan Africa [3].

The productivity of Common bean is very low, 1.69 tons/ha in Ethiopia (CSA, 2017). This low productivity of the crop is mostly due to lack of high yielding varieties adapted to diverse agro ecological conditions, low nutrients and adoption of better agronomic practices. The current national production of common bean in Ethiopia is estimated at 323,317.99 hectares; with a total production of 513,724.807 tons and average productivity of 1.59 tons per hectare [3] in the main season only. Differential responses of crop varieties to acidic soil conditions limit accurate yield estimates and identification of high yielding varieties.

Soil acidity is one of the most serious challenges to agricultural production worldwide, in general, and developing countries in particular. It is mostly distributed in developing countries, where population growth is fast and demand for food is increasing. According to Mesfin [9], about 40.9% of the Ethiopian total land is affected by soil acidity. However the recent study showed that about 43% of the Ethiopian arable land is affected by soil acidity (Ethiosis, 2014). In Ethiopia, vast areas of land in the Western, Southern, South-western, and North-western and even the central highlands of the country, which receive high rainfall, are thought to be affected by soil acidity [9] attributed to various factors including continuous cropping (in many areas mono-cropping) without the use of the required amount of inputs, increasing use of ammonium based inorganic fertilizer, and concentration of CO_2 in the atmospheric; the problem of soil acidity in the country is apparently increasing both in area coverage and severity of the problem.

Increased soil acidity causes solubilization of Al^{3+}, which is the primary source of toxicity to plants at pH below 5.5, and deficiencies of P, Ca, Mg, N, K and micronutrients [9]. Among these constraints, Al toxicity and Phosphorus deficiency are the most important ones, due to their ubiquitous existence and overwhelming impact on plant growth [7], which limits crop growth and development that adversely affects crop production. Soil acidity is often an insidious soil degradation process, developing slowly, although indicators, such as falling yields, leaf discolorations in susceptible plants, lack of response to fertilizers may show that soil pH is falling to critical levels. The study areas are one of such areas with very strongly acidic soil. If it is not corrected, acidification can continue until irreparable damage takes in the soil. Therefore, the adjustment and maintenance of soil acidity is very important management of acidic soils to increase crop production using different mechanisms (approaches).

Lime and fertilizer management practices are primary importance for proper management of soil acidity. It is often not practicable for resource-poor farmers to apply high rates of lime, as well as, mineral fertilizers [13]. Therefore, there is a need to develop practicable or the best alternative soil acidity mitigating strategy. For these reasons, development of common bean varieties adapted to acid soil is a promising alternative or supplement to liming and related agronomic practices. Low pH tolerance often coexists with tolerance to Al toxicity and low P [8]. Tolerance levels have, however, been reported to be influenced by crop genetic background [1]. Foy *et al.* reported the existence of wide genetic variability among and within the species in crops for tolerance to soil acidity [5]. According to Rao, the genetic improvement of crops for Al toxicity tolerance is a less costly complementary approach, for low fertility agricultural systems [10]. Thus, selection of genotypes with high adaptability to acid soils is one of the best approaches to increase productivity of soybean. Malate and citrate exudation has been reported to contribute to Al tolerance in wheat and rye [15]. Therefore, the objectives of this study were: To identify acid tolerant high yielding and promising common bean varieties adapted to different agro-ecologies of acid soil and responded to lime and phosphorus management.

2. Materials and Methods

2.1. Description of the Study Site

The field experiments were conducted at Jimma Agricultural Research Center and Mettu Agricultural Research sub-station, South Western Ethiopia (Table 1), which are characterized by extreme to strong acidic soil and low soil phosphorus.

Table 1. *Agro-ecological characteristics of the experimental sites.*

Testing Location	Altitude (m.a.s.l)	Location	Annual mean RF (mm)	Annual mean Temperature (°C)		Soil
				Min	max	
Jimma	1750	7^0 46'N 36^0E	1754	11	26	Reddish brown
Mettu	1550	35°35' 0"E	1835	12	27	Reddish brown

Source: JARC Agro-meteorology (2016)

2.2. Treatments and Experimental Design

The treatments comprised of two factors namely; four soil amendments (control, phosphorus fertilizer alone, lime alone and phosphorus plus lime) and fifteen different common bean varieties (SER 119, SER 125, Naser, Gofat, Roba, Goberasha, Melka, Awash-1, Dimtu, Ayenew, Bashbash, Dame, Awash Melka, Iboda, and GLP2). The treatments were laid out in a split plot design with three replications. The soil amendments were applied as main plots, where as the common bean varieties were assigned to sub-plot.

The lime requirement (LR) of the soil for the plots was determined based on EA or acid saturation of the experimental soil for each location. Calcium carbonate was used as the source of lime and the whole doses of lime of the respective main plot treatment were broadcasted uniformly by hand and mixed in the top 15 cm soil layer, a month before sowing, to mix lime with soil properly. Phosphorus fertilizer recommended (46 kg P_2O_5 ha^{-1} from Triple Super Phosphate) [12] was applied at planting and mixed with the soil.

2.3. Statistical Analysis

The data was subjected to analysis of variance (ANOVA) using Statistical Analysis System [11] 9.3 Version software using proc GLM procedure. List significant different (LSD) tests was used to separate significantly differing treatment means after treatment effects were found significant at P ≤

0.05.

3. Result and Discussion

3.1. Performance of Common Bean Varieties at Individual Location

There were highly significant differences among common bean variety, seasons and amendments for grain yield and above ground biomass at Mettu. The interaction of amendments X variety X seasons was also highly significant for grain yield and above ground biomass at Mettu. At Mettu the highest grain yield (2703.7Kg/ha) was recorded at lime with phosphorus treated from SER 119 variety during the second year of the experimentation, and the lowest grain yield (242.2Kg/ha) was obtained at the control soil conditions from Goberasha variety during the second year of the experiment (Table 2). This result showed that application of lime with phosphorus to acidic soil resulted in yield increment over lime and phosphorus untreated ones. In agreement with this result, Hirpha reported 25.7% yield increment due to addition of lime over lime untreated soil [6]. Further, Fageria *et al*. also reported the increase of common bean grain yield by 45% due to liming on Oxisols [4].

The highest aboveground biomass (6.44t/ha) was recorded from SER 119 variety under lime and phosphorus treated during the second year of experimentation, while the lowest aboveground biomass (0.56t/ha) was recorded from Goberasha variety under control soil condition of first year (Table 2). This result showed that the addition of lime to acidic soil had a paramount influence on above ground biomass of common bean verities. In agreement with this result, Fageria *et al*. also reported that addition of lime resulted in 40% dry matter increase in common bean [4].

Similar to Mettu at Jimma also, the variety, seasons and amendments were significantly different for grain yield and pod number per plant. The amendments X variety X season's interaction was also highly significant for number of pod per plant and grain yield at Jimma. Significantly higher grain yield (2073.4 and 2017.5 Kg/ha) was produced by variety SER 119 at Jimma under phosphorus treated alone and lime with phosphorus treated respectively during the second year (Table 3). Significantly higher pod per plant (18.47 and 17.8) was produced by variety SER 119 at Jimma under lime with phosphorus treated and phosphorus treated alone respectively during the second year (Table 3).

Table 2. *Mean values of grain yields and AGB as affected by interaction of amendments, varieties and season at Mettu.*

Varieties	**Years**	**Yield Kg/ha**				**Agb t/ha**			
		L	**C**	**P**	**LP**	**L**	**C**	**P**	**LP**
SER 119	Year 1	1181.7	396.3	1080.9	2159.5	2.22	0.69	1.82	4.12
	Year 2	1704.0	673.8	2257.5	2703.7	3.85	1.34	5.33	6.44
Naser	Year 1	1001.5	782.8	747.4	1637.1	2.08	1.22	1.53	2.68
	Year 2	1880.5	790.8	1648.7	2474.6	3.98	1.85	3.47	5.187
SER 125	Year 1	821.3	633.4	874.3	1604.7	1.29	1.29	1.77	3.01
	Year 2	1031.6	563.1	1977.8	2306.4	2.59	1.85	4.86	5.60
Gofat	Year 1	786.2	516.9	606.9	1529.3	1.20	0.93	0.93	2.36
	Year 2	1041.3	620.2	1632.6	2266.7	2.17	1.34	3.10	4.54
Roba	Year 1	579.2	239.7	501.9	1169.1	1.06	0.71	1.02	2.94
	Year 2	1526.1	730.3	1701.8	2235.4	3.33	1.57	3.89	5.74
Awash-1	Year 1	392.8	454.4	530.2	1038.3	0.74	1.44	1.16	2.50
	Year 2	1444.3	1864.4	2204.7	1963.2	3.05	4.17	3.98	5.69
Ayenew	Year 1	756.0	639.3	844.6	1277.8	1.94	1.29	1.48	2.13
	Year 2	1814.3	785.8	1730.1	2073.0	3.98	1.89	4.26	4.95
Melka	Year 1	1054.4	619.6	503.4	1090.1	1.75	1.22	1.02	2.13
	Year 2	1624.4	1322.7	2021.1	1893.4	3.33	2.68	4.44	4.17
Iboda	Year 1	516.1	429.1	346.9	966.80	1.02	0.88	0.65	2.92
	Year 2	675.6	452.0	1819.2	1864.4	1.62	1.34	3.98	4.35
GLP 2	Year 1	937.0	563.2	735.4	1428.2	1.94	1.34	1.20	3.75
	Year 2	1310.7	816.5	1264.2	1812.5	3.15	2.45	3.33	4.54
Dimtu	Year 1	755.0	477.8	369.8	968.00	1.85	1.25	0.69	2.17
	Year 2	1538.8	951.5	1552.5	1686.5	4.07	2.50	3.70	4.95
Goberasha	Year 1	658.8	242.2	317.1	996.50	1.62	0.56	0.60	1.99
	Year 2	980.0	541.3	940.2	1460.1	2.17	1.20	2.13	3.79
Bashbash	Year 1	586.0	329.4	540.1	1103.0	1.34	0.65	1.25	2.27
	Year 2	1174.6	556.7	932.2	1364.0	2.77	1.44	2.96	3.47
Awash Melka	Year 1	450.6	468.0	257.5	924.40	1.34	1.16	0.69	2.54
	Year 2	1340.8	327.2	547.7	853.50	2.93	1.46	1.25	2.31
Dame	Year 1	887.3	676.7	484.8	1058.2	1.66	1.67	1.16	2.22
	Year 2	980.5	703.5	1314.7	1183.7	3.06	1.99	3.01	4.44
LSD		**520.23**				**1.48**			
CV		**29.86**				**37.55**			

Where, L=lime alone, C=control, P=phosphorus alone, LP= both lime and phosphorus treated, LSD=list significant different, AGB= above ground biomass, CV= coefficient of variation.

Table 3. *Mean values of yields and pod per plant as affected by interaction of amendments, varieties and seasons at Jimma.*

Varieties	Years	Yield Kg/ha				Pod per plant			
		L	C	P	LP	L	C	P	LP
SER 119	Year 1	718.10	797.7	792.8	1020.9	9.47	9.13	11.13	11.13
	Year 2	1474.2	1678.5	2017.5	2073.4	14.27	11.93	18.47	17.8
Gofat	Year 1	778.90	477.30	602.7	585.20	8.40	8.60	8.870	9.40
	Year 2	1559.7	1417.0	1575.5	1879	12.40	10.93	15.07	14.93
SER 125	Year 1	926.60	1088.8	796.8	973.0	9.47	9.73	9.470	10.00
	Year 2	1621.9	1533.7	1602.9	1838.3	13.33	10.20	15.00	14.53
GLP 2	Year 1	536.30	555.90	626.3	690.20	10.07	11.00	11.60	9.30
	Year 2	1263.8	1281.8	1477.5	1787.6	12.73	10.60	12.80	16.20
Ayenew	Year 1	1013.8	828.90	605.9	1240.6	10.00	8.53	10.20	11.07
	Year 2	1692.0	1593.8	1492.4	1778.4	13.73	11.93	11.67	15.80
Naser	Year 1	566.00	649.30	517.3	985.4	10.40	9.93	9.730	8.40
	Year 2	1413.4	1281.2	1437.4	1719	12.47	12.07	17.33	16.13
Dimtu	Year 1	947.80	1322.5	550.0	964.9	10.73	10.47	10.47	9.87
	Year 2	1441.0	1421.4	1458.4	1695	15.33	11.60	12.60	14.00
Bashbash	Year 1	999.00	1426.9	738.70	1088.2	10.00	13.00	9.200	10.80
	Year 2	1324.6	1496.8	1608.5	1651.5	16.40	13.73	12.33	14.07
Melka	Year 1	595.70	808.00	523.30	531.6	7.80	6.80	6.870	7.67
	Year 2	1301.7	1308.3	1354.6	1602.7	9.67	7.53	8.330	9.07
Awash-1	Year 1	169.60	82.900	316.0	90.0	14.27	7.87	14.10	12.97
	Year 2	1328.2	1284.7	1397.5	1473.7	21.13	15.73	20.73	16.67
Dame	Year 1	393.40	556.10	239.0	390.4	7.53	7.20	7.800	7.07
	Year 2	1234	1427.9	1082	1380.2	6.93	7.53	7.73	7.93
Roba	Year 1	951	1137.7	882.8	931.3	9.60	9.20	11.13	10.27
	Year 2	1267.4	1245.2	1248.4	1417.3	17.73	14.75	17.27	18.13
Iboda	Year 1	567	595.6	274.2	520.6	8.20	7.73	6.33	7.60
	Year 2	1107.5	829.5	880	1194.7	8.40	7.53	10.00	10.27
Goberasha	Year 1	479.5	549.6	192.2	618.9	8.33	7.93	7.87	8.20
	Year 2	875.9	831.6	754.9	1127	9.80	7.27	9.67	8.87
Awash Melka	Year 1	566.5	695.8	532.6	617.5	12.80	9.27	9.80	10.33
	Year 2	822.8	862.7	1107.8	957.8	12.00	12.80	18.33	12.07
LSD		395.61				3.38			
CV		23.703				18.74			

Where, L=lime alone, C= control, P= phosphorus treated, LP=lime with phosphorus treated, CV= coefficient of variation, LSD= list significant different.

3.2. Performance of Common Bean Varieties over Amendments, Seasons and Locations

The analysis of variance showed that the main effect of location, amendment, seasons and Variety and the interaction effect of location X amendment X seasons X Variety had a significant effect on grain yield and number of pod per plant. The highest number of pod per plant (18.33 and 18.33) was recorded at Jimma from SER 119 and Awash Melka varieties during second year, and the highest grain yield (2.73t/ha) was recorded at Mettu from combined lime with phosphorus treated SER 119 variety at second year of experiment (Table below). The result of combined analysis revealed that variety SER 119 had the highest grain yield (1438 Kg/ha), whereas variety Awash Melka had the lowest grain yield (713.4 Kg/ha), and the result of combined analysis for individual amendment also revealed that variety SER 119 had the highest grain yield (1989.4Kg/ha) at lime with phosphorus treated, where as variety Goberasha had the lowest grain yield (541.2Kg/ha) at control soil condition. This result showed that application of lime to acidic soil resulted in yield increment over lime untreated ones. In agreement with this result, Hirpha reported 25.7% yield increment due to addition of lime over lime untreated soil [6]. In this study generally, common bean varieties showed inconsistent performance in terms of grain yield and pod per plant across location under both amended regimes which indicated the presence of environmental and amendment influence on the performance of the variety.

Table 4. *Mean values of yields as affected by interaction of amendments, varieties, seasons and locations.*

Varieties	Years	Yield t/ha							
		Year 1 (2017)				Year 2 (2018)			
	Loc	L	C	P	LP	L	C	P	LP
SER 119	Mettu	1.200	0.400	1.067	2.13	1.700	0.677	2.23	2.73
	Jimma	0.700	0.800	0.777	1.00	1.477	1.700	2.00	2.067
Naser	Mettu	1.00	0.777	0.777	1.633	1.90	0.800	1.677	2.47
	Jimma	0.533	0.677	0.533	0.967	1.433	1.277	1.433	1.733
SER 125	Mettu	0.833	0.633	0.900	1.600	1.00	0.577	1.977	2.30
	Jimma	0.933	1.100	0.800	0.933	1.633	1.533	1.600	1.877
Gofat	Mettu	0.777	0.500	0.600	1.533	1.033	0.633	1.633	2.27
	Jimma	0.800	0.477	0.600	0.600	1.577	1.433	1.577	1.877

Varieties	Years	Yield t/ha							
		Year 1 (2017)				Year 2 (2018)			
	Loc	L	C	P	LP	L	C	P	LP
Roba	Mettu	0.577	0.277	0.500	1.677	1.500	0.733	1.677	2.23
	Jimma	0.967	1.100	0.877	0.933	1.277	1.233	1.277	1.400
Awash-1	Mettu	0.400	0.477	0.533	1.033	1.433	1.800	2.20	1.977
	Jimma	0.200	0.100	0.300	0.067	1.333	1.277	1.377	1.500
Ayenew	Mettu	0.733	0.633	0.833	1.277	1.800	0.800	1.733	2.067
	Jimma	1.00	0.833	0.600	1.277	1.700	1.577	1.477	1.800
Melka	Mettu	1.033	0633	0.500	1.067	1.600	1.300	2.00	1.90
	Jimma	0.633	0.833	0.533	0.533	1.300	1.277	1.33	1.600
Iboda	Mettu	0.533	0.433	0.377	0.967	0.677	0.477	1.833	1.877
	Jimma	0.533	0.633	0.877	0.533	1.133	0.833	0.300	1.200
GLP 2	Mettu	0.967	0.577	0.777	1.433	1.300	0.833	1.277	1.833
	Jimma	0.533	0.577	0.633	0.677	1.300	1.300	1.477	1.800
Dimtu	Mettu	0.777	0.500	0.377	0.967	1.500	0.967	1.533	1.700
	Jimma	0.967	1.33	0.533	0.967	1.433	1.400	1.477	1.700
Bashbash	Mettu	0.577	0.33	0.533	1.100	1.200	0.577	0.900	1.377
	Jimma	0.967	1.433	0.733	1.100	1.377	1.500	1.633	1.677
Goberasha	Mettu	0.677	0.233	0.33	1.00	1.00	0.533	0.933	1.477
	Jimma	0.477	0.533	0.200	0.600	0.900	0.833	0.777	1.133
Dame	Mettu	0.877	0.677	0.477	1.067	0.967	0.700	1.300	1.177
	Jimma	0.400	0.577	0.233	0.377	1.233	1.433	1.100	1.377
Awash Melka	Mettu	0.477	0.477	0.277	0.933	1.33	0.300	0.533	0.877
	Jimma	0.600	0.700	0.577	0.633	0.833	0.833	1.100	0.967
LSD		0.4706							
CV		27.67							

Where, L=lime alone, C= control, P= phosphorus treated, LP=lime with phosphorus treated, CV= coefficient of variation, LSD= list significant different.

Table 5. *Mean values of pod per plant as affected by interaction of amendments, varieties, seasons and locations.*

Varieties	Years	Pod per plant							
		Year 1 (2017)				Year 2 (2018)			
	Locations	L	C	P	LP	L	C	P	LP
Awash-1	Mettu	6.67	7.67	7.00	9.33	7.33	13.3	11.3	13.3
	Jimma	14.3	8.00	14.0	13.0	21.3	15.67	20.67	17.0
Awash Melka	Mettu	5.00	6.33	5.00	7.33	7.33	4.67	4.67	7.33
	Jimma	13.0	9.33	9.67	10.3	12.0	13.0	18.3	12.3
Roba	Mettu	6.67	5.00	6.67	7.67	8.00	6.00	8.67	9.67
	Jimma	9.33	9.00	11.0	10.3	17.67	14.67	17.3	18.3
SER119	Mettu	10.3	4.00	10.0	11.3	9.33	5.00	9.33	12.3
	Jimma	9.33	9.00	11.0	11.0	14.0	12.0	18.3	18.0
Naser	Mettu	10.0	7.67	8.67	9.67	8.33	6.67	8.33	10.67
	Jimma	10.67	10.0	9.67	8.33	12.67	12.0	17.3	16.0
GLP 2	Mettu	6.67	6.33	5.67	9.00	6.33	6.67	7.67	7.33
	Jimma	10.3	11.0	11.67	9.00	13.0	10.67	13.0	16.3
Bashbash	Mettu	6.00	4.67	7.00	7.67	6.33	5.00	8.00	7.67
	Jimma	10.0	13.00	9.00	10.67	16.3	13.67	12.3	14.0
Ayenew	Mettu	6.67	6.67	7.00	7.67	8.67	5.00	9.00	10.3
	Jimma	10.0	8.67	10.0	11.0	13.67	11.67	11.67	16.0
Gofat	Mettu	6.00	5.33	7.33	8.33	5.67	5.67	7.33	10.0
	Jimma	8.33	8.67	9.00	9.33	12.67	11.0	15.0	14.67
SER 125	Mettu	6.67	5.67	8.33	9.33	7.33	5.00	11.0	10.3
	Jimma	9.33	9.67	9.33	10.0	13.67	10.0	15.0	14.3
Dimtu	Mettu	6.33	6.67	5.67	6.33	7.67	8.00	7.67	10.67
	Jimma	10.67	10.3	10.33	10.00	15.0	11.67	12.67	14.3
Iboda	Mettu	4.00	4.67	5.00	6.00	5.00	5.00	7.33	8.67
	Jimma	8.00	7.67	6.33	7.67	8.67	7.33	10.0	10.3
Goberasha	Mettu	5.67	4.00	5.00	7.33	6.00	4.00	6.00	7.00
	Jimma	8.33	8.00	7.67	8.33	10.0	7.67	9.67	9.00
Melka	Mettu	6.00	4.33	5.33	6.00	6.67	4.33	6.67	6.33
	Jimma	7.67	7.00	6.67	7.33	9.67	7.33	8.67	9.33
Dame	Mettu	5.00	4.00	4.33	7.00	6.00	5.00	5.00	5.00
	Jimma	7.67	7.33	7.67	7.00	7.00	7.33	7.67	8.00
LSD		3.549							
CV		24.19							

Where, L=lime alone, C= control, P= phosphorus treated, LP=lime with phosphorus treated, CV= coefficient of variation, LSD= list significant different.

Table 6. *Over year combined mean value of grain yield (Kg/ha) of fifteen common bean varieties at individual location under different amendments.*

Varieties	Mettu		Jimma		Combined	
	C	LP	C	LP	C	LP
SER 119	535.1	2431.6^{a}	1238.1^{abc}	1547.2^{a}	886.6^{abc}	1989.4^{a}
SER 125	598.3^{bc}	1955.5^{bc}	1311.3^{ab}	1405.6^{abc}	954.8^{abc}	1680.6^{bc}
Naser	786.8^{abc}	2055.8^{ab}	965.2^{cdef}	1352.2^{abcd}	876.6^{abc}	1704^{b}
Ayenew	712.6^{bc}	1675.4^{cdef}	1211.3^{abcd}	1509.5^{ab}	962^{abc}	1592.5^{bcd}
Dimtu	714.7^{bc}	1327.2^{efg}	1371.9^{a}	1329.9^{abcd}	1043.3^{a}	1328.6^{efg}
Gofat	568.5^{c}	1898.0^{bcd}	947.2^{cdef}	1232.1^{bcd}	757.8^{cde}	1565.1^{bcde}
Melka	971.1^{ab}	1491.8^{defg}	1058.1^{bcde}	1067.2^{def}	1014.6^{ab}	1279.5^{fgh}
Roba	485^{c}	1702.3^{bcde}	1191.4^{abcd}	1174.3^{cde}	838.2^{abc}	1438.3^{cdef}
Bashbash	443.1^{c}	1233.5^{fgh}	1461.8^{a}	1369.8^{abc}	952.4^{abc}	1301.7^{fg}
GLP 2	689.8^{bc}	1620.3^{cdef}	918.9^{def}	1238.9^{bcd}	804.3^{bcd}	1429.6^{def}
Awash -1	1147.7^{a}	1500.8^{defg}	704.5^{f}	781.8^{f}	926.1^{abc}	1141.3^{ghi}
Dame	690.1^{bc}	1121^{gh}	992^{cdef}	885.3^{ef}	841.1^{abc}	1003.1^{ij}
Iboda	440.6^{c}	1415.6^{efg}	712.5^{f}	857.6^{f}	576.6^{de}	1136.6^{ghi}
Goberasha	391.8^{c}	1228.3^{fgh}	690.6^{f}	872.9^{f}	541.2^{e}	1050.6^{hij}
Awash Melka	397.6^{c}	889^{h}	779.3^{ef}	787.6^{f}	588.4^{de}	838.3^{j}
Mean	638.25	1569.74	1036.94	1160.799	837.566	1365.38
Level of significant	*	**	*	**	**	**
LSD	397.55	427.07	304.85	291.75	233.9	249.41
CV	37.246	16.266	17.577	15.027	16.77	10.9223

Where, C=control, LP= Lime with phosphorus treated, CV= coefficient of variation, LSD= list significant different, Note: Means with the same letters are statistically not significant (p>0.05) different from each other

Table 7. *Over year and amendment combined mean value of grain yield (Kg/ha) of fifteen common bean varieties at individual location.*

Varieties	Mettu	Jimma	Combined
SER 119	1483.3^{a}	1392.6^{ab}	1438.0^{a}
SER 125	1276.9^{abc}	1358.4^{abc}	1317.7^{ab}
Naser	1421.3^{ab}	1158.7^{cd}	1290.0^{ab}
Ayenew	1194.0^{abcd}	1360.4^{abc}	1277.2^{ab}
Dimtu	1021^{cdef}	1350.9^{abc}	1185.9^{bc}
Gofat	1233.3^{abcd}	1089.6^{de}	1161.5^{bc}
Melka	1231.4^{abcd}	1062.6^{de}	1147.0^{bc}
Roba	1093.6^{bcdef}	1182.8^{bcd}	1138.2^{bc}
Bashbash	838.3^{efg}	1415.8^{a}	1127.1^{bc}
GLP 2	1155.1^{abcde}	1078.9^{de}	1117.0^{bcd}
Awash -1	1324.2^{abc}	743.2^{f}	1033.7^{cde}
Dame	905.6^{defg}	938.6^{ef}	922.1^{efg}
Iboda	928.1^{defg}	785.1^{f}	856.6^{efg}
Goberasha	810^{fg}	781.7^{f}	795.9^{fg}
Awash Melka	643.3^{g}	783.4^{f}	713.4^{g}
Mean	1103.956	1098.872	1101.414
Level significant	**	**	**
LSD	331.07	219.38	207.47
CV	17.93	11.94	11.26

Where, CV= coefficient of variation, LSD= list significant different, Note: Means with the same letters are statistically not significant (p>0.05) different from each other

3.3. Tolerance and Susceptibility Index of Common Bean Varieties to Acid Soils

Variability for soil acidity tolerance and susceptibility among common bean varieties has been observed in this study (Table 8). The tolerance and susceptibility rating of specific entries depended upon the particular criterion (based on observed characters) used to denote their tolerance and susceptibility. Compared with other varieties, variety SER 119 produced the highest tolerance values based on grain yield, which showed statistically non significant different with other some varieties i.e. Ayenew, Bashbash, Dimtu, Naser and SER 125 (Table 8). In general, even if SER119 variety showed high tolerant value, this variety fail to reach national average under control soil condition, but more than national average under recommended lime and phosphorus treated soil condition, which showed this variety is well responded to lime and phosphorus than tolerant to acid soil condition.

Table 8. *Tolerance and susceptibility index of common bean varieties for yield at individual locations and combined on acid soil.*

Locations	**Jimma**		**Mettu**	**Combined**	
Varieties	**TI**	**SI**	**TI**	**TI**	**SI**
Bashbash	1.853^{a}	-0.070^{ab}	1.353	1.77^{a-d}	0.270^{cd}
SER 119	1.777^{ab}	0.1970^{ab}	3.23^{a-d}	2.513^{a}	0.150^{d}
Ayenew	1.74^{ab}	0.210^{ab}	3.17^{a-d}	2.270^{abc}	0.41^{abc}
SER 125	1.693^{ab}	0.020^{ab}	2.97^{a-d}	2.29^{ab}	0.43^{abc}
Dimtu	1.67^{abc}	-0.063^{ab}	2.42^{a-e}	1.990^{a-d}	0.203^{d}
Roba	1.31^{bcd}	-0.010^{ab}	2.103^{b-e}	1.750^{bcd}	0.42^{abc}
Naser	1.217^{cde}	0.280^{a}	4.017^{ab}	2.123^{abc}	0.483^{ab}
Gofat	1.08^{de}	0.270^{ab}	2.81^{a-e}	1.703^{bcd}	0.527^{a}
Melka	1.06^{de}	0.013^{ab}	3.527^{abc}	1.85^{a-d}	0.203^{d}
GLP 2	1.057^{def}	0.243^{ab}	2.77a-e	1.647^{b-e}	0.447^{abc}
Dame	0.82^{efg}	-0.137b	2.00^{b-e}	1.230^{d-g}	0.170^{d}
Iboda	0.58^{fg}	0.183^{ab}	1.67^{cde}	0.933^{efg}	0.487^{a}
Awash Melka	0.560^{g}	-0.030^{ab}	0.84^{e}	0.703^{g}	0.293^{bcd}
Goberasha	0.557^{g}	0.1830^{ab}	1.23^{de}	0.81^{fg}	0.473^{ab}
Awash -1	0.520^{g}	0.070^{ab}	4.24^{a}	1.517^{c-f}	0.550^{a}
Mean	1.165	0.085	2.53	1.673	0.366
Level significant	**	NS	*	*	**
LSD	0.47	0.3819	2.0184	0.7656	0.1911
CV	24.51	26.9	47.88	27.44	31.29

Where, TI=tolerance index, SI= Susceptibility index, CV= coefficient of variation, LSD= list significant different, Note: Means with the same letters are statistically not significant (p>0.05) different from each other

4. Conclusion and Recommendations

Overall, the current study revealed that the availability of varietal difference among common bean varieties under both amended and unamended acid soil conditions. The highest grain yield (1.043 t/ha) under control soil conditions obtained from this result is still below the national average (1.59t/ha), but more than the national average under lime and phosphorus treated plots (1.989t/ha), which shows that the variety was responded to lime and phosphorus than tolerant to acid soil. Increasing yield and pod number in lime and phosphorus treated plot, were found in some common bean varieties. Variety of SER 119 was the tolerant variety based on the ASAI (acid soil adaptability index) for yield based on combined analysis tolerant index and showed high yields under control soil condition at Jimma. These two characters cannot be enough to use as the criteria of common bean tolerance in low pH or acid soil toxicity. Tolerance criteria may be laid on root parameter i.e. root length, number of lateral roots, and root dry weight, because of the use of root parameter as a criterion in common bean tolerance in low pH or acid soil toxicity should be studied further to ensure the increasing root elongation, number of lateral roots and nutrients uptake to support its tolerance. So the root data should be considered during data collection for the future.

In this study, common bean varieties showed inconsistent performance in terms of grain yield across location under both amended regimes, even if the same varieties at the same location showed inconsistent performance over the year, which indicated the presence of weather climatic, environmental and amendment influence on the performance of the variety, except SER 119 variety which showed similar performance across locations and years under recommended lime and phosphorus treated plots only. Generally, until tolerant variety is selected for resource poor farmers, SER 119 variety is selected for those farmers who have the capacity to apply lime with phosphorus based on the yield performance at both locations and also this variety is included in the future work of further selection trials.

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