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Original Research

Response to Soil Acidity of Common Bean Genotypes (*Phaseolus vulgaris* L.) Under Field Conditions at Nedjo, Western Ethiopia

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Abstract

Soil acidity has become a serious threat to crop production in most highlands of Ethiopia in general and in the western part of the country in particular. A field experiment was conducted to evaluate soil acidity tolerant on 25 genotypes of common bean (*Phaseolus vulgaris* L.) on lime treated and untreated acid soils. The genotypes were evaluated based on morpho-agronomic parameters. Soil acidity had an effect on maturity, growth and yield of the tested genotypes. High significant(P<0.01) differences were observed among genotypes for days to maturity, leaf area index, plant height, number of pods per plant, pod length, hundred seed weight, grain yield, pod harvest index and harvest index in lime treated and untreated soils. Considerable variability exists among the genotypes tested based on the growth, and yield components measured for soil acidity tolerance. The genotypes gave higher yield and yield components when grown in lime treated soil than lime untreated with average yield reduction of 26% due to soil acidity effect. Relative grain yield was calculated as the ratio of grain yield in lime untreated to lime treated soil also showed higher significant differences among the tested genotypes. Genotypes such as Dimtu, new BILFA 58, Beshbesh, SER176, new BILFA51 and new BILFA 61 gave higher absolute and relative yield, whereas Dinknesh, Chore, Nasser and new BILFA 60 gave lower absolute grain and relative yield. Moreover, the great variability of 25 common bean genotypes exhibited a good potential to screening large germplasm of common bean for soil acidity tolerance and develop a cultivar that are tolerant to soil acidity in the country.

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INTRODUCTION

Acid soils make up approximately 30% of the world's total land area and more than 50% of the world's potentially arable lands, particularly in the tropics and subtropics (Kochian *et al.*, 2004). When the pH drops to below 5, aluminium (Al) is released into the soil solution and becomes the single most important factor limiting crop production on 67% of the total acid soil area in the World (Eswaran *et al.*, 1997). The extent of soil acidity in Africa is difficult to quantify. Eswaran *et al*. (1997) estimated that 28.8% of the African continent has acid surface soils and 19.6% has sub soil acidity problems. Soil acidity has become a serious threat to crop production in most highlands of Ethiopia in general and in the western part of the country in particular. Currently, it is estimated that about 40% of the total arable land of Ethiopia is affected by soil acidity (Abdenna *et al.*, 2007; Mesfin, 2007).

Common bean is currently produced on about 331,708.15 hectares of land in Ethiopia; with a total production of 387,802.3 tonnes with an average yield of 1.17 tonnes/ha (CSA, 2012). Common bean is generally less adapted to acid soil environments and improving Al resistance of common bean to reduce the dependence of small-scale farmers on lime and nutrient inputs is a major challenge (Rao, 2001). However, efforts to develop adapted genotypes indicate that there are genotypic differences in Al resistance in the bean germplasm (Rao, 2001; Rangel *et al*., 2005; Manrique *et al*., 2006).

To mitigate severe yield reductions, smallholder farmers in the western and eastern Wollega zones have been abandoning their land temporarily (fallowing) or even permanently in some areas. However, owing to the increasing population pressure, abandoning farmland temporarily or permanently has become an untenable option. Therefore, the farmers are now opting for managing soil fertility to sustain productivity. Nevertheless, for both logistics and economic reasons, it is often not practicable for resource-poor farmers to apply high rates of lime as well as mineral fertilizers. There is, therefore, a need to develop practicable alternatives. For these reasons, development of cultivars adapted to acid soil complexes is a promising alternative or supplement to liming and related agronomic practices. Hence, the selection of common bean genotypes/varieties adapted to acid soil conditions of western Ethiopia is necessary to ensure economic stability to many farmers who cannot afford application of liming material. Common bean varieties with the capacity to tolerate acidic soil conditions will also produce high yields in areas where liming is not feasible due to high acidity conditions in the subsoil. Therefore the aim of this study was to assess the differential response of common bean genotypes of different origin to soil acidity in terms of growth, yield, and yield related traits under field conditions.

MATERIALS AND METHODS

Description of the Study Site

The field study was conducted at Nedjo TVET Collage, which is located in western Wollega zone of the Oromia Regional State at the latitude of 9°5′N and longitude of 35°45'E in western Ethiopia. The site has an elevation of 1735 meters above sea level with a gently undulating slope (0-5%). The rainfall distribution is mono-modal with the long rains occurring from April to October. The annual rainfall during the experimental period was 1386 mm with mean minimum and maximum temperatures of 12^{0}C and 26^{0}C, respectively. The soils are acidic, well drained, deep, and reddish brown in colour. The physical and some chemical properties of the soil in the study area before sowing and after harvesting the crop for both lime treated and untreated soil are indicted in Table 1.

Table 1: Physical and Chemical properties of the soil for field experiment site at Nedjo, western Ethiopia.

No.	Soil Analysis	Field (Nejo)		
		Before sowing	After Harvest	
			Unlimed	Limed
1	Texture	Silt loam	Loam	loam
	Clay (%)	12		
	Sand (%)	35		
	Silt (%)	50		
2	pH(H_2O)	4.45	4.39	5.14
3	Organic matter (%)	5.03	4.96	5.75
4	Total N (%)	0.25	0.27	0.30
5	Available P(BrayII)(ppm)	7.96	6.95	10.43
6	EC	0.090	0.123	0.11
7	Cations (meq/100 g soil)			
	Ca	1.54	1.75	5.0
	Mg	2.26	3.10	2.50
	K	0.85	1.07	1.12
	Al +H	5.19	6.2	2.70
	Al	4.95	5.56	2.38
8	Relative proportion of cations			
	Ca/Mg	0.68	0.56	2.0
	Mg/K	2.66	2.90	2.23
	Ca + Mg/K	4.47	4.53	6.7
9	Acid saturation	52.7	51.2	23.9
10	ECEC	9.84	12.12	11.32
11	CEC	22.18	24.13	25.08

Soil Sampling, pH Calibration and Soil Analysis

Soil samples were collected from the experimental site at the depth of 0-20 cm using an auger. Ten soil samples were taken from each arm of the shaped pattern. All samples were bulked and composited and a 1 kg composite sample was taken for analyzing physical and chemical properties of the soil. The samples were air-dried, disaggregated and sieved through a 2 mm sieve and analyzed (Thompson and Banerjee, 1991).

The field experiment was conducted with both lime treated and untreated soils. Before liming, the amount of lime required to raise the soil pH to a level suitable for the growth of common bean was determined. Thus, to calculate the lime requirement of the soil, triplicate dry soil samples each weighing one kg were thoroughly mixed with 0, 400, 800, 1200, 1600, 2000, 2400, 2800, 3200, 3600, 4000 and 4400 mg of calcium carbonate ($CaCO_3$). Each soil sample weighing one kilogram was filled in a polyethylene bags having the capacity of three kg soil. The samples were then thoroughly mixed with the rate of lime to be tested. Then, the samples were saturated with water. When the soil mixed with the lime was well saturated, the mouth of each polyethylene bags filled with the soil-lime mix was closed to avoid evaporation. By the third day, the excess water was drained after opening the mouth of the polyethylene; the samples were incubated under room temperature for a period of four weeks.

Soil pH was determined in 1:2.5 (w/v) soils to water (H_2O) suspension ratio using a glass electrode attracted to a digital pH meter. Total N was determined by the micro-kjeldahl procedure as described by Jackson (1958). Available P in the soil samples was determined following the procedure of Bray-II method (Bray and Kurtz, 1945). Organic carbon was determined following the wet digestion method as described by Walkley and Black (1934). Percent organic matter was estimated as: % OM= % organic Carbon X 1.72

Exchangeable potassium was extracted by 1 N ammonium acetate (1.0N NH_4AOC) and the concentration was estimated using a flame photometer after extraction. Cation Exchange Capacity and exchangeable bases were determined by extracting with 1.0 M ammonium acetate at pH 7. Aluminium was determined by titrating with NaOH, and Ca and Mg by titration with EDTA. Exchangeable acidity was determined by extracting the soil samples with 1M KCl solutions and titrating with standardized NaOH as described by McLean (1965). Effective cation exchange capacity (ECEC) was estimated by summation of exchangeable bases and exchangeable acidity (Al and H). Percent acid saturation was calculated as: % acid saturation= (Exchangeable Acidity/ECEC)*100.

Planting Material

Twenty-five common bean varieties and bred-lines were evaluated against soil acidity under field condition. The improved genotypes included in the evaluation were genotypes released by Melkassa and Bako Agricultural Research Centres (Table 2). To have a sizable variability among the genotypes, accessions or varieties that are assumed sensitive, resistant, and mildly resistant to soil acidity were included. All the genotypes included in the evaluation have a bushy and semi prostrate growth habit, and vary in seed colour and size. The genotypes were evaluated based on growth, yield, and yield components.

Liming Material

A lime is an agricultural material capable of neutralizing soil acidity, i.e., increasing soil pH. The lime ($CaCO_3$) was thoroughly and evenly distributed to the plots according to the pre-determined rates of the treatment and was worked into the soil four weeks before sowing the seed of the genotypes. The liming material used in this study had a purity of 93.7 % $CaCO_3$. Lime was applied prior to planting at the rate of 2.16 kg per plot according to the result obtained from the pH calibration curve (Figure 1). The amount of lime applied was equivalent to 9 tonnes $hectare^{-1}$.

Treatments and Experimental Design

The treatments consisted of 25 genotypes and two types of soil amendment (lime treated and untreated). The experiment was laid out as a randomized complete block design and replicated two times per treatment. Each plot consisted of three rows of bean plants occupying a 2 m long distance and a 1.2 m width. The distance between successive plots and adjacent blocks were 1 m and 1.5 m, respectively. The spacing between plants and rows was 10 cm and 40 cm, respectively. The data were reported as the ratio of grain yield in the lime untreated plot to that in the lime treated plot to adjust for differences in yield potential without acid soil stress according to Johnson *et al*. (1997).

Planting

Two seeds of common bean genotype were sown at each planting hole. Two weeks after planting, the seedlings were thinned to one per hill, thereby retaining the recommended population of 250,000 common bean plants per hectare. Fertilizer (DAP) was applied at the rate of 92 kg ha^{-1}(49 mg) per plot and mixed well with soil at sowing. All other recommended agronomic management practices were applied uniformly to all genotypes grown in the field. The first weeding was done two weeks after germination, and then weeding was performed as required until the plants started flowering.

Table 2: Common bean genotypes screened for soil acidity tolerance, on field at Nejo, during the 2009/10 cropping season.

No.	Genotype	Seed Source	Provenance	Growth habit	Adaptation	Seed colour	HSW (g)	Type of germplasm
1	New Bilfa 38	1	CIAT	III	LSF	pinto	29.4	CRL
2	New Bilfa 57	1	CIAT	II	LSF	cream	18.8	CRL
3	New Bilfa 50	1	CIAT	III	LSF	red	14.3	CRL
4	New Bilfa 60	1	CIAT	III	LSF		21.4	CRL
5	New Bilfa 58	1	CIAT	III	LSF	yellow	27.9	CRL
6	Gabisa (Vax-2)	2	CIAT	II	WO	tan	22.5	R
7	New Bilfa 51	1	CIAT	III	LSF	black	17.2	CRL
8	New Bilfa 61	1	CIAT	III	LSF	dark	24.0	CRL
9	New Bilfa 45	1	CIAT	II	LSF	black	19.4	CRL
10	New Bilfa 46	1	CIAT	II	LSF	red	19.5	CRL
11	Awash 1	1	CIAT	II	CRV	white	14.2	R
12	Awash Melka(PAN182)	1	CIAT	II	AAE	White	12.4	R
13	Argane	1	CIAT	II	CRV & SA	White	13.7	R
14	Nasser (Dicta-105)	1	CIAT	III	AAE	Red	18.0	R
15	Dimitu (DOR-554)	1	CIAT	II	AAE	Red	16.4	R
16	Dinknesh	1	CIAT	II	CRV & SA	Red	17.8	R
17	Roba 1	1	CIAT	II	AAE	Cream	18.9	R
18	Beshbesh(melk97) cross 5	1	CIAT	II	SE	Cream	13.9	R
19	Anger(EMP-376)	2	CIAT	I	BA	Dark red	18.4	R
20	Chore (STTT-165-92)	1	CIAT	II	RV, S, SW & E	White	15.2	R
21	SER 16	1	CIAT	II	DT.	Red	17.9	bred
22	SEA 5	1	CIAT	II	DT	cream	22	bred
23	SER78	1	CIAT	II	DT	Dark red	18.5	bred
24	SER 128	1	CAIT	II	DT.	Dark red	21.0	bred
25	SER 176	1	CIAT	II	DT	Red	17.0	bred

I-Determinate bushy; II = indeterminate bushy; III- indeterminate prostrate; IV = indeterminate climbing, 1 = Melkassa Agricultural Research Centre; 2= Bako Agricultural Research Center CIAT = International Centre for Tropical Agriculture,. HSW- hundred seed weight, CRV-Central Rift Valley ,DT-drought tolerant, SE=south Ethiopia, BA- Bako Area, AAE- across all Environments ,R- cross line, RV- rift valley, S- south, SW- south western, WO- western oromiya, LSF- low soil fertility, R- released.

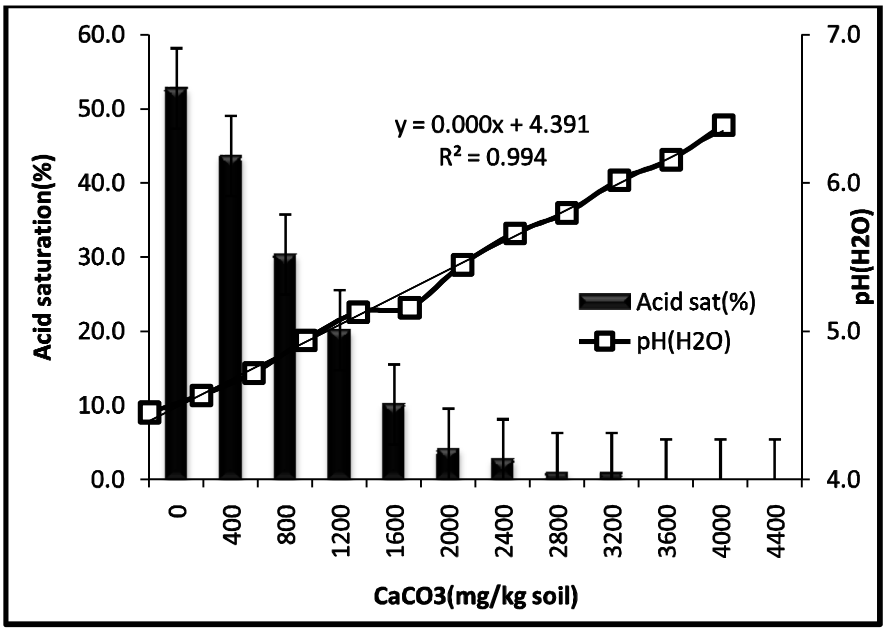

Figure 1: pH (a) and acid saturation (b) determined through incubation at different rates of lime applied to the soil.

Data Collection and Measurements

Date of 50% flowering (number of days from planting to when 50% of plants in field had at least one open flower), and days to physiological maturity (number of days from planting to when 75% plants in a field had at least 90% of their pods dried (Tesso, 2007) were recorded. Plant height and leaf area were recorded from central rows of five plants taken from each plot just at flowering. LAI was calculated as the ratio of total leaf area to ground area occupied by the plant. Leaf area was determined by using CID-202 leaf area meter (CID, Inc., USA).

At harvest, number of pods per plant and the number of primary branches per plant were recorded from five randomly selected plants. The number of seeds per pod and pod length were determined from 10 randomly selected pods from each plot. Grain yield was recorded from the entire plot after counting the number of plants harvested from each plot. Hundred seed weight was determined from 100 seeds randomly sampled from all plants harvested per plot. Harvest index (HI) was calculated as the proportion of seed weight to the above ground dry weight (stem + leaves + pod + seed) at harvest. Pod harvest index was calculated as the weight of dry pod (seed + pod shell) divided by total above ground biomass (Setegn, 2006). Eventually, based on the results of the data analysis, the genotypes were compared and grouped in to sensitive and tolerant ones.

Statistical Analysis

Data were subjected to analysis of variance using the GLM procedure of SAS software (SAS, 2004). Genotypes were considered as fixed effects whereas replications were reckoned as random effects in the statistical model. The PROC CORR from SAS was used to calculate the correlation of genotypic means. Treatment means that exhibited significant differences were separated using the student-Neuman Keuls test (SNK) at 5% level of significance (SAS, 2004).

RESULTS

Pre-cropping Soil Fertility Status and pH Curve

The physical and chemical properties of the experimental soil are shown in Table 1. Analysing the particle size distribution of the soil revealed the textural class of loamy sand. The soil is very strongly acidic, has high contents of organic matter, total nitrogen and low content of available phosphorus before planting the seeds. Exchangeable Ca and Mg in the soil were low and medium, respectively, where as exchangeable K was high in this soil. The aluminium content of the soil was very high, while the ratio of cations, Ca/Mg, Mg/K, and Ca + Mg/K was low for the three cations. In addition, the experimental soil had a high exchangeable acidity and acid saturation (Table 1). The result obtained from the pH curve indicated that soil pH (H_2O) increased in response to the applied lime, and resulted in decreased acid saturation (Figure 1). From the result obtained, application of lime at the rate of 2000 mg $CaCO_3$/kg (9 t ha^{-1} lime) soil led to increase in soil pH to optimum level for common bean growth (Fageria *et al*., 1997). Therefore, this rate was selected to treat the whole experimental soil. At this rate of lime, the pH of the soil increased from 4.45 to 5.4, the exchangeable acidity reduced to 0.39 from 5.19 and acid saturation dropped from 52.7 to below 4.13%, which are optimum for common bean growth (Figure 1).

Effect of Soil Acidity on Phenology and Growth

Phenological stages and growth parameters of common bean genotypes grown under lime treated and untreated soils are indicated in Table 3. Soil acidity had a marked influence on common bean maturity and growth. Common bean genotypes showed significant differences in days to pod setting, maturity, plant height and leaf area index in response to being grown under both lime treated and untreated soils. The variation was highly significant (P<0.01) for all parameters except for days to flowering in lime untreated soil. Plants of all genotypes were significantly taller and had higher values of leaf area index, but lower number of days to flowering and maturity when grown in lime treated than in untreated soil (Table 3). These results signified that application of lime hastened flowering and maturity of the plants whilst increasing plant height and leaf area (Table 4). On average, the genotypes reached days to 50 % flowering significantly earlier when lime treated than when they were lime untreated. Thus, plants grown in lime treated soil reached days to 50% flowering earlier than plants grown in the lime untreated soil by about 9%. Similarly, plants grown in the lime treated soil were quicker to reach physiological maturity by about 15.5% than plants grown in the lime untreated soil.

Gabisa, New Bilfa 61, and SER 16 reached physiological maturity significantly earlier under lime treated than under untreated soils. However, genotypes Dimtu and Beshbesh, reached physiological maturity significantly earlier under lime untreated soil condition than under lime treated condition. The maturity times of all other genotypes were in statistical parity under lime treated and untreated soils (Table 4). The results of this study revealed that the bred lines matured early whereas the improved ones matured relatively late.

Table 3: Mean squares of phenological stages, growth, yield and yield components of common bean genotypes grown on limed and unlimed soil on field.

Source of variation	Liming	Genotypes	ERROR	Total
Parameters				
Days to 50% flowering	UL	44.33^{NS}	24.24	1646
	L	6.83***	0.77	182.5
Days to 50% pod setting	UL	87.25*	38.21	3011.4
	L	21.39***	5.25	642.02
Days to 50% maturity	UL	43.4***	7.06	1212.02
	L	32.47***	4.37	884.3
LAI	UL	0.998***	0.281	30.68
	L	1.03*	0.46	37.47
Plant height(cm)	UL	312.7***	78.1	10058.7
	L	416.3*	100.1	12492.5
Branch number per plant	UL	0.33^{ns}	0.25	14.28
	L	0.857*	0.358	37.55
Number of pods per plant	UL	27.23***	2.17	706.95
	L	37.3***	35.8	5.01
Number of seeds per pod	UL	0.77^{NS}	0.51	30.9
	L	1.02***	0.277	31
Pod length	UL	2.18***	0.33	60.9
	L	1.05***	0.37	34.4
100 seed weight	UL	34.85***	0.96	861.2
	L	34.89***	1.13	866.73
Grain Yield (g/P)	UL	10.67	0.557	270.9
	L	13.5***	0.895	347.02
Grain Yield (t/ha)	UL	0.667***	0.035	16.89
	L	0.849***	0.056	27.72
Biomass Yield (t/ha)	UL	1.18^{ns}	0.45	40.3
	L	1.61^{ns}	0.983	68.75
Pod harvest index	UL	0.154**	0.037	4.69
	L	0.087^{ns}	0.056	3.88
Harvest index	UL	0.0149**	0.0011	0.386
	L	0.0073***	0.002	0.22
Relative yield		219.9*	86.4	7474.2

Where, UL – unlimed , L- Limed, *(0.01-0.05), **(0.001-0.01), ***(*P*<0.001), NS- non-significant (*P*>0.05)

Table 4: Phenology and growth of common bean genotypes grown under limed and unlimed soil at Nedjo on field during 2009/10 main cropping season.

Genotypes	DF		DM		LAI		PH(cm)	
	UL	L	UL	L	UL	L	UL	L
NB 38	54.0^{f}	44.0^{ns}	91.0^{c}	75.5^{bcd}	5.72^{a}	4.40^{ab}	44.6^{bc}	52.3^{abcd}
NB57	58.0^{bcd}	55.0^{ns}	87.5^{c}	79.5^{bcd}	3.80^{ab}	3.60^{ab}	48.2^{bc}	66.4^{abcd}
NB 50	62.0^{a}	57.0^{ns}	91.0^{c}	83.5^{bc}	3.73^{ab}	5.60^{ab}	30.4^{c}	41.5^{cd}
NB 60	55.5^{cdef}	51.0^{ns}	92.0^{c}	77.5^{bcd}	2.74^{b}	4.30^{ab}	56.3^{abc}	78.3^{abc}
NB58	54.5^{ef}	56.5^{ns}	90.5^{c}	81.0^{bcd}	3.94^{ab}	3.80^{ab}	57.7^{abc}	84.5^{a}
Gabisa	58.0^{bcd}	53.5^{ns}	103.0^{a}	80.5^{bcd}	3.31^{ab}	3.95^{ab}	39.1^{bc}	59.3^{abcd}
NB51	58.0^{bcd}	54.5^{ns}	90.5^{c}	82.0^{bcd}	4.93^{ab}	5.50^{ab}	53.9^{abc}	57.9^{abcd}
NB 61	57.0^{bcdef}	49.0^{ns}	94.0^{bc}	72.0^{d}	3.10^{ab}	3.35^{b}	60.1^{abc}	63.1^{abcd}
NB 45	56.0^{cdef}	52.0^{ns}	88.5^{c}	76.0^{bcd}	3.71^{ab}	5.55^{ab}	37.0^{bc}	42.7^{bcd}
NB 46	56.0^{cdef}	55.0^{ns}	92.5^{c}	81.5^{bcd}	3.67^{ab}	4.25^{ab}	38.9^{bc}	43.2^{bcd}
Awash 1	56.5^{bcdef}	47.5^{ns}	90.0^{c}	77.0^{bcd}	5.01^{ab}	3.80^{ab}	67.7^{ab}	70.2^{abcd}
Awash M.	56.5^{bcdef}	41.5^{ns}	90.5^{c}	81.5^{bcd}	4.82^{ab}	4.90^{ab}	37.3^{bc}	39.7^{cd}
Argane	55.0^{def}	53.5^{ns}	89.5^{c}	78.0^{bcd}	3.87^{ab}	4.30^{ab}	35.1^{bc}	46.9^{abcd}
Nasser	55.5^{cdef}	50.5^{ns}	89.0^{c}	75.5^{bcd}	4.29^{ab}	4.20^{ab}	79.9^{a}	81.7^{ab}
Dimitu	56.5^{bcdef}	58.0^{ns}	90.0^{c}	91.5^{a}	3.52^{ab}	4.25^{ab}	46.2^{bc}	67.4^{abcd}
Dinknesh	59.5^{b}	56.5^{ns}	90.5^{c}	83.0^{bc}	3.99^{ab}	4.50^{ab}	44.2^{bc}	51.9^{abcd}
Roba 1	58.5^{bc}	56.0^{ns}	94.5^{bc}	82.0^{bcd}	4.16^{ab}	4.05^{ab}	35.7^{bc}	37.5^{d}
Beshbesh	57.5^{bcde}	56.5^{ns}	90.5^{c}	86.0^{ab}	3.35^{ab}	4.55^{ab}	42.2^{bc}	52.2^{abcd}
Anger	57^{bcdef}	54.5^{ns}	99.0^{ab}	77.5^{bcd}	4.61^{ab}	4.35^{ab}	39.4^{bc}	47.1^{abcd}
Chore	57.0^{bcdef}	58.5^{ns}	100.5^{a}	85.0^{abc}	4.64^{ab}	4.54^{ab}	30.6^{c}	35.9^{d}
SER 16	54.5^{ef}	44.0^{ns}	87.5^{c}	71.5^{d}	5.14^{ab}	4.65^{ab}	50.5^{bc}	53.8^{abcd}
SEA 5	55.0^{def}	52.0^{ns}	87.0^{c}	76.5^{bcd}	3.03^{ab}	6.20^{a}	33.9^{bc}	47.9^{abcd}
SER 78	55.5^{cdef}	49.0^{ns}	90.5^{c}	74.5^{dc}	4.98^{ab}	4.70^{ab}	38.9^{bc}	41.3^{cd}
SER 128	54.5^{ef}	46.5^{ns}	88.5^{c}	74.5^{dc}	4.61^{ab}	5.20^{ab}	64.9^{abc}	74.5^{abcd}
SER 176	54.5^{ef}	49.0^{ns}	88.0^{c}	75.5^{bcd}	5.1^{ab}	3.83^{ab}	41.1^{bc}	47.2^{abcd}
Mean	56.5	52	91.4	79.14	3.89	4.45	46.2	55.4
CV (%)	1.55	9.5	2.3	3.4	13.6	15.3	19.2	18.1
SE±	0.88	4.9	2.09	2.66	0.53	0.68	8.84	10.01

Means with the same letters in a column are not significantly different at 5 % level of significance. UL- unlimed;, L- Limed; DF- days to flowering; DM–days to maturity; PH- plant height; CV- coefficient of variation;, Ns–non-significant; SE= standard error , NB- new BILFA

Effect of Soil Acidity on Yield and Yield Components

Soil acidity had significant effect on yield and yield components of common bean genotypes (Table 3). Highly significant (*P*<0.001) differences were observed among genotypes for number pods per plant, pod length, grain yield, hundred seed weight and harvest index in both soils regimes. However, non-significant differences were found among common bean genotypes for number of seeds per pod, number branches per plant and biomass yield in lime untreated soil. On average, the genotypes gave higher yield and yield components in lime treated soil (Table 5). SER materials gave higher number of pods per plant but shorter pods in both lime treated and untreated soil (Table 5). Generally, longer pods were harvested from lime treated soil than from untreated soil (Table 5). Thirteen genotypes, namely, Awash 1, Awash Melka, Argane, Nasser, Dimitu, Dinknesh, Anger, Chore, SER 16, SEA 5, SER 78, SER 128, and SER176 gave statistically non-significant pod length. The pod lengths of all other genotypes obtained under both lime treated and untreated soil conditions were in statistical parity.

Under the lime untreated soil condition, the minimum pod length was obtained for the genotype named Chore whereas the maximum was obtained for the genotypes named new BILFA 58. The highest hundred seed weight was recorded for BILFA materials (New Bilfa 38 and New Bilfa 58) both under lime treated and untreated soils. On the other hand, the lowest hundred seed weight was recorded for new BILFA 50, Awash melka, Argane, Beshbesh, Chore and Awash 1 under lime untreated soil (Table 5). However, the released varieties produced generally lower hundred seed weights than often reported by research centres under both lime treated and untreated soils. In general; lime application to the soil increased hundred seed weight of common genotypes by about 3.54%.

Table 5: Yield components of common bean genotypes grown under lime untreated and treated acid soil in field at Nedjo.

Genotypes	NPP		Pod Length(cm)		100 S. weight(g)		HI	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
NB 38	16^{cdefg}	18^{ef}	8.9^{abc}	10.6^{a}	29.4^{a}	30.9^{a}	0.42^{bc}	0.41^{a}
NB 57	18^{bcdef}	23^{bcdef}	8.8^{abcd}	10.9^{a}	18.8^{efg}	17.3^{fghi}	0.34^{cdefg}	0.33^{abcd}
NB 50	19^{bcdef}	23^{bcde}	8.4^{abcdef}	9.4^{ab}	14.3^{ijk}	15.9^{ghi}	0.34^{cdefg}	0.40^{a}
NB 60	12^{gh}	14^{ef}	9.1^{abc}	10.3^{ab}	21.4^{bcde}	26.0^{b}	0.24^{efghi}	0.32^{abcd}
NB 58	20^{bcde}	21^{cdef}	10.0^{a}	10.6^{a}	27.9^{a}	30.4^{a}	0.37^{cd}	0.35^{abcd}
Gabisa	14^{fgh}	19^{ef}	8.4^{abcdef}	9.9^{ab}	22.5^{bc}	21.7^{cd}	0.21^{hi}	0.23^{cd}
NB 51	18^{bcdef}	21^{def}	8.7^{abcde}	9.8^{ab}	17.2^{ghi}	18.1^{defghi}	0.40^{bc}	0.31^{abcd}
NB 61	20^{bcde}	22^{cdef}	8.8^{abcde}	10^{ab}	24.0^{b}	22.4^{c}	0.32^{cdefgh}	0.33^{abcd}
NB 45	20^{bcde}	24^{bcde}	9.2^{abc}	10.3^{ab}	19.4^{defg}	18.4^{defghi}	0.33^{cdefg}	0.32^{abcd}
NB 46	19^{bcdef}	22^{bcdef}	7.8^{bcdefg}	9.1^{ab}	19.5^{defg}	18.3^{defghi}	0.35^{cdefg}	0.40^{a}
Awash 1	15^{cdefgh}	22^{cdef}	6.6^{defg}	8.5^{ab}	14.2^{ijk}	15.0^{i}	0.32^{cdefg}	0.33^{abcd}
Awash M.	20^{bcde}	24^{bcde}	8.2^{abcdef}	8.6^{ab}	12.4^{k}	15.4^{hi}	0.34^{cdefg}	0.38^{abc}
Argane	16^{cdefg}	23^{bcde}	$8.1^{abcdefg}$	8.1^{b}	13.7^{jk}	14.7^{i}	0.27^{defgh}	0.32^{abcd}
Nasser	18^{bcdef}	24^{bcde}	6.6^{efg}	9.1^{ab}	18.0^{fgh}	20.0^{cdef}	0.28^{defgh}	0.25^{bcd}
Dimitu	15^{efgh}	18^{ef}	7.6^{bcdefg}	9.6^{ab}	16.4^{ghij}	16.8^{i}	0.35^{cdef}	0.30^{abcd}
Dinknesh	11^{h}	17^{ef}	6.4^{fg}	8.9^{ab}	17.8^{fgh}	18.6^{defghi}	0.15^{i}	0.21^{d}
Roba 1	15^{defgh}	19^{ef}	7.6^{bcdefg}	9.6^{ab}	18.9^{efg}	19.7^{cdefg}	0.24^{efghi}	0.35^{abcd}
Beshbesh	20^{bcde}	21^{cdef}	$8.0^{abcdefg}$	9.5^{ab}	13.9^{jk}	17.0^{fghi}	0.35^{cdefg}	0.37^{abcd}
Anger	13^{gh}	18^{ef}	7.1^{cdefg}	9.9^{ab}	18.4^{efgh}	19.2^{fghi}	0.22^{ghi}	0.24^{cd}
Chore	12^{gh}	17^{ef}	6.1^{g}	9.2^{ab}	15.2^{hijk}	16.8^{fghi}	0.24^{fghi}	0.23^{cd}
SER 16	26^{a}	30^{ab}	7.1^{cdefg}	9.1^{ab}	17.9^{fgh}	17.6^{efghi}	0.40^{bc}	0.42^{a}
SEA 5	22^{b}	32^{a}	9.6^{ab}	10^{ab}	22.0^{bcd}	21.2^{cde}	0.42^{bc}	0.39^{ab}
SER 78	18^{bcdef}	20^{def}	7.0^{cdefg}	8.6^{ab}	18.5^{efgh}	18.1^{defghi}	0.36^{cde}	0.28^{abcd}
SER 128	21^{bc}	29^{abc}	7.3^{cdefg}	9.4^{ab}	21.0^{cdef}	19.2^{cdefgh}	0.49^{ab}	0.33^{abcd}
SER176	21^{bcd}	28^{abcd}	8.3^{abcd}	8.9^{ab}	17.0^{ghi}	18.4^{defghi}	0.52^{a}	0.33^{abcd}
Mean	17.4	21.8	7.96	9.5	18.79	19.48	0.32	0.33
CV (%)	8.5	10.3	7.22	6.4	5.22	5.45	9.84	11.99
PR (%)	20.2		16.2		3.54		3.03	

UL- unlimed, L- Limed, CV- coefficient of variation, Ns – non-significant, SE= standard error, PR- percent reduction [1-(UL/L)]*100.

The effect of lime was greatest for pod number per plant with an average increase of 20.2% for the lime treated soil than for the untreated soil. Seed number per pod was less sensitive to soil acidity, with a mean increase of only 15.4% in lime treated soil than untreated soils. Similarly, pod length was reduced by 16.2% on average, suggesting that reduction in grain yield due to soil acidity stress may have stemmed from the effect on pod number per plant.

Yield responses showed that the grain yield was significantly (P<0.01) affected by lime application. In general, liming resulted in a mean improvement in grain yield for all genotypes over no lime application (Table 3). The magnitude of increase in grain yield and total dry biomass yield due to liming was 25.7 and 27.6%, respectively over the no lime treatment. Higher absolute grain yield in the lime untreated soil was recorded for the genotypes new BILFA 58, SER 176, SEA 5, and Beshbesh (Figure 2). However, Gabisa, Chore, and Anger produced the lowest absolute grain yields on the lime untreated soil. Soil acidity also affects the harvest index of the genotypes. However, lime application increased harvest index and pod harvest index of the genotypes (Table 6). The highest harvest index was recorded for SER materials (SER 176 and SER 128) both under lime untreated and treated soil condition. The lowest harvest index was recorded for Dinknesh, Gabisa, Roba 1, Anger and Chore, in lime untreated soil.

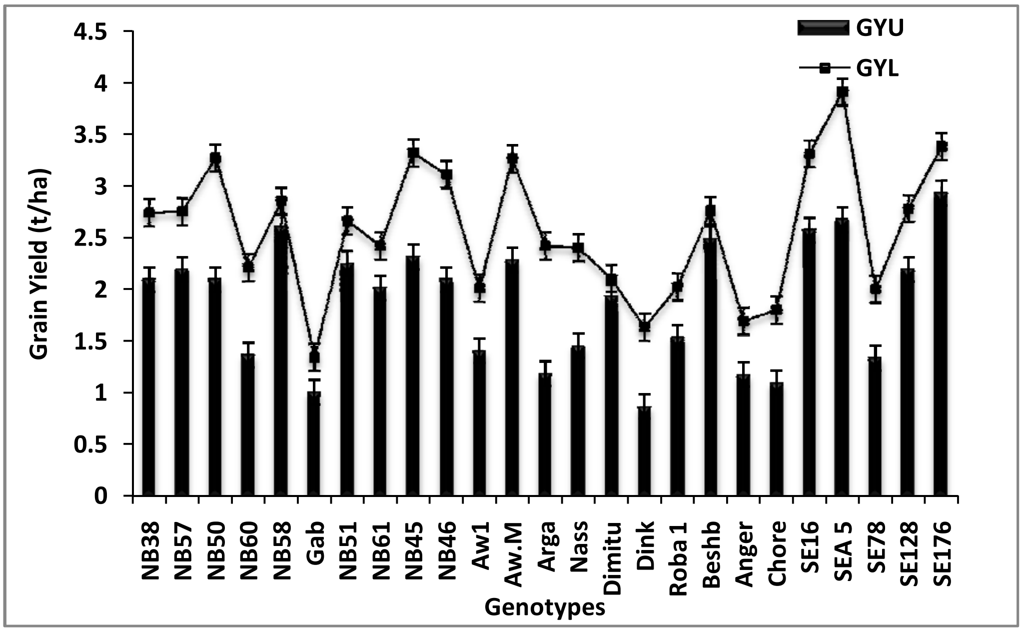

Figure 2: Grain Yield (GY) of common bean genotypes tested for soil acidity tolerance under lime (L) treated and untreated (U) soil at Nedjo, Western Ethiopia.

Table 6: Average values of Grain yield, Biomass, pod harvest index (PHI), Harvest index (HI) & hundred seed weight (HSW) of common bean genotype grown under lime treated and untreated soils at Nedjo.

Treatment	DF	DP	DM	LAI	PH	BN	NPP	NSP	PL
Unlimed	56.5^a	70.9^a	91.4^a	3.9^b	46.1^b	5.3^b	17.4^b	4.7^b	7.9^b
Limed	52.0^b	64.8^b	79.2^b	4.5^a	55.4^a	6.7^a	21.8^a	5.5^b	9.5^a
PR	8.7	9.3	15.5	12.6	16.7	21.8	20.2	14.6	16.3
Mean	54.3	67.8	85.3	4.2	50.8	5.99	19.6	5.1	8.7
***CV* (%)**	6.5	6.8	2.8	14.8	18.7	10.80	9.6	12.2	6.7

Treatment	GY(g/p)	GY(t/ha)	BY(t/ha)	PHI	HI	HSW
Unlimed	7.4^b	1.9^b	3.6^b	1.01^a	0.33^a	18.8^b
Limed	10.3^a	2.6^a	5.3^a	1.05^a	0.34^a	19.5^a
PR	8.9	2.3	4.6	22.9	0.33	19.1
Mean	25.7	25.7	27.6	3.81	2.9	3.5
CV (%)	9.6	9.5	19.97	1.03	11.6	5.3

Where, GY= grain yield, DM= dry matter, PHI= pod harvest Index, HI = Harvest index, HSW =hundred seed weight (g), t/ha= tonne per hectare CV=coefficient variation

Relative vs. Absolute Yield

Relative grain yields and percent yield reductions of the genotypes in response to being grown in lime treated and untreated soils are shown in Figure 3. The variations in relative yields of common bean genotypes were significant (Table 3). The genotypes produced significantly higher yields under lime treated soil than under untreated soil, exceeding the yield obtained in the lime untreated soil by about 7.7–47.3%. On average, the genotypes produced 74% relative grain yield when grown on lime untreated soil than when grown in lime treated soil. Thus, on average the grain yields of the genotypes reduced by about 26% in response to growing in lime untreated soil. Higher relative grain yields were recorded for Dimitu, new BILFA 58, Beshbesh, SER 176, new BILFA 51 and new BILFA 61 genotypes. However, Dinknesh, Chore, Nasser and new BILFA 60 produced very low grain yields or the grain yields suffered most reductions in response to growing them in the lime untreated soil (Figure 3).

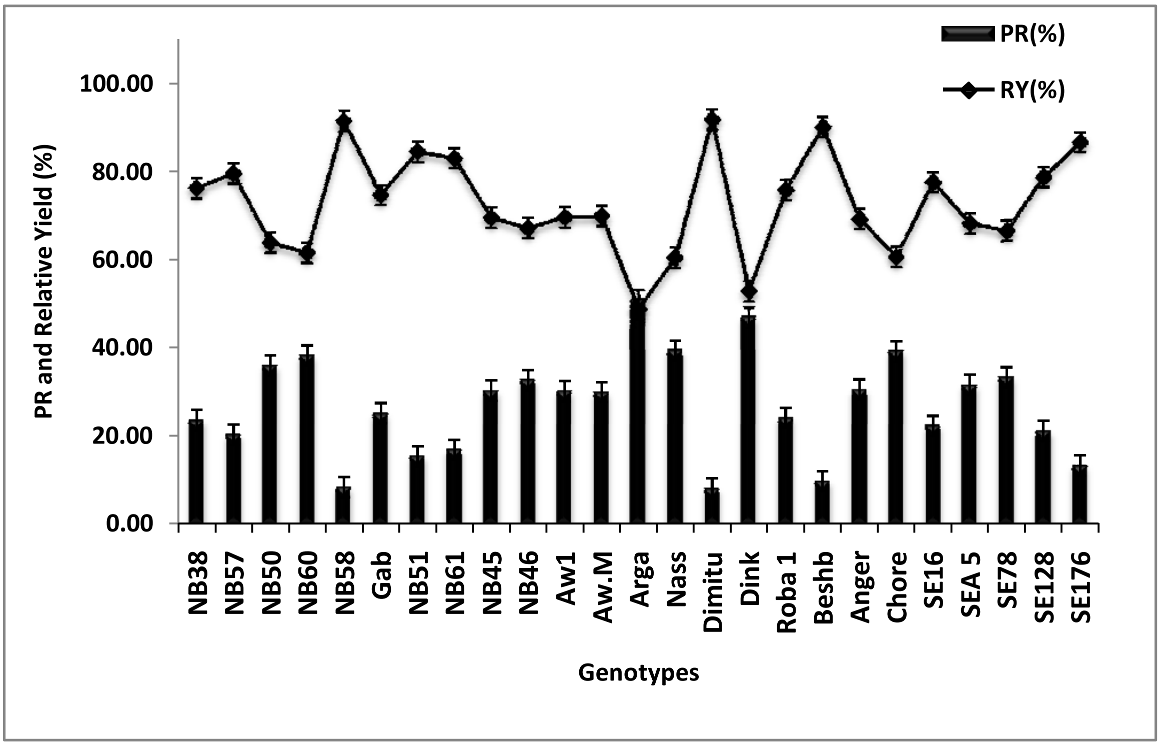

Figure 3: Relative Yield (RY%), and percent reduction (PR) of common bean genotypes tested for soil acidity tolerance under lime treated and untreated soil at Nedjo, Western Ethiopia.

Correlation Analysis

The correlation coefficients between some measured traits (selected pairs of parameters) are presented in Table 7 for lime treated and untreated soils. Correlation analysis indicated that there was a positive and significant correlation between days to flowering and days to maturity in both soil regimes. Days to flowering and maturity had also significant and positive correlations with the number of branches per plant (Table 7). However, days to flowering had a strong and negative correlation with number of pods per plant, and harvest index under both lime treated and untreated soil conditions. Days to maturity had a strong and negative relation with number of pods per plant, grain yield, pod harvest index and harvest index in soil not treated with lime (Table 7). Pair wise correlation analysis indicated a strong and positive relation of grain yield with number of pods per plant, number of seeds per pod, and pod length in lime untreated soil (Table 7). Similarly, grain yield of common bean genotypes were highly and positively correlated with the number of pods per plant and number of seeds per pod in lime treated soil (Table 7). Number of pods per plant was positively correlated with plant height in both lime treated and untreated soils. However, the correlation between plant height and pod length was weak and negative in lime untreated soil. In both lime treated and untreated soils 100 seed weight was strongly and positively correlated with pod length and weakly correlated with the number of pods in lime untreated soil. However, 100 seed weight was weakly and negatively correlated with number of seeds per pod in both liming regimes soil. Harvest index was negatively correlated with physiological maturity in both soils. However, harvest index was strongly and positively correlated with number of pods per plant, number of seeds per pod, and grain yield and negatively correlated with biomass yield in both soil types (Table 7).

Table 7: Pearson correlation analysis for growth, yield and yield components of common bean genotypes grown under lime untreated (1st) and lime treated (2nd) soil on field at Nedjo.

	DF	DM	LAI	PH	BN	NPP	NSP	PL	GY	RY	BY	PHI	HI	HSW
DF	1	0.32	-0.21	-0.30	0.42*	-0.34	0.06	-0.15	-0.35	-0.24	0.37	-0.13	-0.49*	-0.39
DM		1	0.09	-0.28	0.11	-0.58**	-0.28	-0.22	-0.64**	-0.19	0.08	-0.50*	-0.60**	0.09
LAI			1	0.04	0.01	0.06	-0.02	-0.48*	-0.02	-0.09	-0.56**	0.05	0.31	-0.19
PH				1	-0.30	0.10	-0.14	-0.12	-0.02	0.3	-0.24	-0.05	0.13	0.23
BN					1	-0.07	-0.13	0.09	0.08	0.14	0.21	0.19	-0.06	-0.07
NPP						1	0.48*	0.35	.0.84***	0.42*	-0.14	0.66***	0.75***	0.08
NSP							1	0.39	0.54**	0.37	-0.15	0.54**	0.51	-0.08
PL								1	0.59**	0.43*	0.20	0.54**	0.34	0.51**
GY									1	0.62***	-0.05	0.80***	0.83***	0.09
RY										1	-0.08	0.46*	0.54**	0.17
BY											1	-0.26	-0.59**	-0.16
PHI												1	0.76***	0.13
HI													1	0.16
HSW														1

	DF	DM	LAI	PH	BN	NPP	NSP	PL	GY	BY	PHI	HI	HSW
DF	1	0.69***	0.07	-0.07	0.47*	-0.42*	0.03	0.19	0.32	0.09	-0.29	-0.37	-0.12
DM		1	-0.08	-0.13	0.42*	-0.47*	-0.13	-0.01	-0.24	-0.12	-0.04	-0.16	-0.24
LAI			1	-0.32	0.16	0.42*	0.39	-0.11	0.44*	0.40*	-0.07	0.14	-0.40*
PH				1	-0.07	-0.05	-0.37	0.33	-0.13	0.05	-0.20	-0.12	0.48*
BN					1	-0.11	0.08	-0.16	-0.16	0.39	-0.33	-0.39	-0.30
NPP						1	0.53**	-0.17	0.77***	0.34	0.19	0.50**	-0.32
NSP							1	-0.10	0.47*	0.40*	-0.04	0.17	-0.48*
PL								1	0.11	-0.04	0.05	0.11	0.64***
GY									1	0.27	0.51*	0.78***	-0.11
BY										1	-0.47*	-0.37	-0.23
PHI											1	0.81***	0.19
HI												1	0.07
HSW													1

Analysis of Residual Soils

Soil samples collected after the harvest of common bean genotypes were analyzed for different soil properties including pH, organic matter, cation exchange capacity (CEC), electrical conductivity, exchangeable cations (Ca, Mg and K). In addition, a few acidic soil properties such as exchangeable acidity, acid saturation, effective cation exchange capacity and Al concentration were analyzed to estimate the changes that may have occurred upon liming and growing common bean genotypes without liming. The results showed that application of lime caused an increase in pH. The mean magnitude of increase was 0.69 units (Table 1), but growing common bean genotypes on the lime untreated acid soil further decreased the pH of the soil by 0.06 units in this experiment. In general, the result obtained for the soil analysis after crop harvest indicted very strong acid soil (pH_{H2O}, 4.48), low exchangeable cations and their fractions (Table 1). On the other hand, growing common bean genotypes without lime on strong acid soil resulted in an increase in acid saturation. Lime application resulted in decreased acid saturation by half (Table 1). The concentration of available P was very low under lime untreated and low when lime was applied after the crop harvest (Table 1).

DISCUSSION

The bean genotypes responded markedly to soil acidity in which case distinct symptoms of chlorosis of lower leaves as well as absence of root nodules were observed. The chlorosis, which may have been attributable to lack of nitrogen fixation as suggested by Piha and Munns (1987), was distinctly visible especially at early vegetative stage of growth. For a few genotypes, very few and tiny nodules where observed, which were difficult to separate from root and soil. Generally, the genotypes failed to produce nodules at Nedjo site when grown on both lime treated and untreated acid soils. Consistent with the result of his study, Evans *et al. (*1980) reported that nodulation was 10 times more sensitive to acidity than the growth of rhizobium or the legume root alone. In addition similar to the findings of this study, Vargas and Graham (1989) found that soil acidity is a major factor limiting nodulation and nitrogen fixation in common bean. Soil acidity adversely affects nodulation and nitrogen fixation was also reported by Bambara and Ndakidemi (2010) who observed that drastically affected legume-rhizobium symbiosis.

Growing common bean on acid soils significantly affect phenology and growth of the genotypes.

However, lime application reduces the toxicity effects of soil acidity and improves the growth performance of the genotypes. In general the genotypes reached physiological maturity significantly earlier when lime was applied than when lime was not applied. Similar results also were reported by Meda and Furlani (2005), the presence of Al in nutrient solution caused a delay in the vegetative growth of the tropical leguminous plants used as cover crops in Brazil. Taller plants were observed in response to growing the genotypes under lime treated soil than under untreated soil. Corroborating the results of this study, Oluwatoyinbo *et al*. (2005) reported that plant height was significantly increased by the application of lime. This may be attributed to the toxic effect of soil acidity, which may lead to stunting of plants under lime untreated soil. This suggestion is consistent with the results of Zhang *et al.* (2007) who reported that soil acidity led to Al-induced leaf necrosis. The result of this study is consistent also with that of Foy (1984), who reported leaf yellowing in response to low soil pH and also with that of Wang *et al.* (2006) who stated that soil acidity led to stunted leaf growth. The result of this study agrees also with that of Rout *et al.* (2001) who reported that low soil pH led to late leaf maturity as a result of Al-toxicity.

Considerable variability for soil acidity tolerance among the bred lines and improved genotypes has been observed in this study. Similar results were reported by Rao *et al*. (2004) for acid soil adaptation and Rangel *et al.* (2005) for Al resistance among common bean genotypes. Large genotypic differences among crops also have been reported for Al tolerance by Foy *et al*. (1972) and Noble *et al*., (1985). Similarly, consistent with the results of this study, differing tolerance to aluminium tolerance of genotypes of *Phaseolus vulgaris, Glycine max, Zea mays* and *Avena sativa* were reported earlier by Foy (1988).

The results obtained in this study also revealed that some genotypes, namely, New BILFA 58, SER 176 and Beshbesh, produced significantly higher absolute as well as relative grain yields. On the other hand, only a few genotypes, namely, Dimitu, new BILFA 51, and new BILFA 61, did produce lower absolute yield whilst producing higher relative yield. Therefore, relative yield data should not be used alone as a selection criterion for tolerance to soil acidity. Consistent with this result, Fisher and Scott (1987) showed that equally responsive genotypes may have equal absolute tolerances yield differential between blocks but appear quite different in their yield ratios. Thus, the ratios should be interpreted with caution, or at least not reported alone.

Days to maturity had a stong and negtive relation with number of pods per plant, grain yield, pod harvest index and harvest index in soil not treated with lime. It also had a weak and negtive correlation with grain yield of genotypes grown in soil treated with lime(Table 7). Similar results were also reported by Salehi *et al*. (2008), Assady *et al*. (2005), and Kumar *et al*. (2002) for common bean. As observed from the results, genotypes that produced higher grain yields under both lime untreated and lime- treated soil were early in maturity.

Number of pods per plant was positively correlated with plant height in both unlimed and limed soils. However, the correlation between plant height and pod length was weak and negative in unlimed soil. In line with this result, Arya *et al.* (1999), reported that the number of pods per plant was positively correlated with plant height. In both lime untreated and treated soils 100 seed weight was strongly and positively correlated with pod length and weakly correlated with the number of pods in unlimed soil. However, 100 seed weight was weakly and negatively correlated with number of seeds per pod in both unlimed and limed soil. Similarly, Changezi *et al*. (2005) and Dursum (2007) reported the highest positive correlation with seed yield for the number of pods per plant and 100-seed weight. These results give a clear indication that the grain yield was mutually very closely associated with number of pods per plant, in both unlimed and limed soil. It seems that this is useful characters to select for high yield in common bean breeding programs for soil acidity tolerance.

CONCLUSIONS

Soil acidity problems for common bean production can be overcome by growing genotypes which are adapted to acid soil condition in circumstances where other soil amendment strategies are not readily practical. However, this is not possible until these tolerant genotypes are developed. This study revealed that common bean genotypes differ in tolerance to soil acidity. Although some genotypes exhibited an outstanding performance in terms grain yield and yield related traits, soil fertility improvement through liming would still be very important if economical bean production is to be produced in places with strong acid soil as the one used in this study. Moreover, the great variability of 25 common bean genotypes exhibited a good potential to screening large germplasm of common bean for soil acidity tolerance and develop a cultivar that are tolerant to soil acidity with potential and quality grain on such acid soils in the future.

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