Research article

Response of Soybean Genotypes for Root, Nodulation, Growth, Yield and Yield Components to Lime and Phosphorus Application at Mettu, south western Ethiopia.

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Soybean (*Glycine max* L.) is one of grain legumes that are grown in tropical, subtropical and temperate climates. Acidic soils limit the productive potential of crops because of low availability of basic cations and excess of hydrogen and aluminium in exchangeable forms. This study was conducted to assess the response of soybean genotypes to lime and phosphorus. Treatments were laid out in a split-plot design, whereby four soil amendments were assigned to main plots and fifteen genotypes were assigned to the sub-plots. Treatment means were compared at 5% level of significance using Duncan's Multiple Range Test. The results revealed that genotype x amendment interactions were significant (p<0.01) for all growth, root and nodulation characteristics and yield and yield components. The maximum grain yield of (2120 and 2047.2 kg ha^{-1}) was obtained under Phosphorus alone and combined with lime from HAWASSA-04 variety and PI567046A genotype, respectively with non-significant variation; while the lowest (510.5 kg ha^{-1}) were recorded from SCS-1genotype under the control treatment. Tolerance index value indicated that genotypes BRS238, PI567046A and variety HAWASSA-04 performed well for most of the traits and selected as tolerant. Significant and positive correlations were found for all growth, root and nodulation parameters with grain yield. The result of this study verified that application of lime (3457.8 kg ha^{-1}) and Phosphorus (20 kg ha^{-1}) improved the growth, root and nodulation characteristics yield and yield related traits of soybean genotypes. In conclusion, observation of large variation indicates that selection would be effective to improve soybean genotypes performance on acid soils and identify low Phosphorus tolerant genotype that helps smallholder farmers optimize soybean productivity on acid soils in the study area. Genotypes BRS238, PI567046A and HAWASSA-04 variety are the most tolerant among the tested materials. However, further study is required including more locations and years by considering additional genotypes, to determine the residual effect of phosphorus and lime to reach at a conclusive recommendation.

Key words: *Amendments, Genotypes, Lime, Phosphorus, Soil acidity, Soybean*

INTRODUCTION

Soybean (*Glycine max* L.) is one of grain legumes that are grown in tropical, subtropical and temperate climates. Consideration of the economic and nutritional advantages of soybeans has led many countries to start large scale production of this crop. Currently, the main global importance of soybean is as a key ingredient for livestock feeds (Tinsley, 2009). Soybean is the single most important protein and oil source in dairy meals and poultry feeds. As human food, soybean has more protein than any Pulses, Fish and Meat combined (18% and 11%), respectively. Soybean has 100% more protein than other common crops (Jagwe and Owuor, 2004). It is the only known viable substitute to animal and fish protein, and also it is a multipurpose crop, which can be used for a variety of purposes, including preparation of different kinds of soybean foods and soy milk (Hailegiorgis, 2010). It has various uses as for fortification with other cereal flour e.g., Maize to enhance their nutritional value. Soybean is known for its wide adaptability coupled with its higher productivity per unit area compared to other grain legumes.

Soil acidity is one of the most serious challenges to agricultural production worldwide, in general and developing countries in particular. It comprises 50% of the world's potentially arable land, and thus, is a significant limitation to crop production worldwide (Uexkull and Muter, 1995). According to Ethiosis, (2014) about 43% of the Ethiopian arable land is affected by soil acidity. Attributed to various factors including continuous cropping (in many areas mono-cropping) without the use of the required amount of inputs, and increasing use of ammonium based inorganic fertilizer; the problem of soil acidity in the country is apparently increasing both in area coverage and severity of the problem(Mesfin, 2007). Soil acidity is quantified on the basis of H^+ and Al^{3+} concentrations of soils. It is a complex of numerous factors involving nutrient deficiencies and toxicities, low activities of beneficial micro organisms, and reduced plant root growth, which limits absorption of nutrients and water (Fageria and Baligar, 2008). Al toxicity and Phosphorus deficiency are the most important ones, due to their ubiquitous existence and overwhelming impact on plant growth (Kochian *et al.*, 2004), which limits crop growth and development that adversely affects crop production.

Lime is the major means of ameliorating soil acidy (Anetor and Ezekiel, 2007), because of its very strong acid neutralizing capacity, which can effectively remove existing acid, stimulate biological activity and reduce toxicity of heavy metals. The most efficient crop production on acid soils is the application of both lime and fertilizer, specifically P. Nevertheless, for economic reasons, it is often not practicable for resource-poor farmers to apply high rates of lime, as well as, mineral fertilizers (Uguru *et al.*, 2012). For these reasons, development of soybean varieties adapted to acid soil is a promising alternative or supplement to liming and phosphorus. Thus, selection of genotypes with high adaptability to acid soils is one of the best approaches to increase productivity of soybean. Therefore, the objectives of this study were: To identify soybean genotypes that tolerates low pH and low P soil, and soybean genotypes that respond to optimum lime and P management.

MATERIALS AND METHODS

Description of the Study Site

The study was carried out at Mettu Agricultural Research Sub Center during 2017/18 main cropping season. The sub-center is located at 600 km away from Addis Ababa in Iluabbabora Zone of the Oromia Regional National State. It is located at latitude 8°19' 0" N longitude 35°35' 0"E at an altitude of 1550 m.a.s.l and it has been characterized as Tepid to cool humid mid highlands with annual rainfall distribution pattern of 1835 mm/annum. The mean annual temperature ranges from 12 to 27 ^{0}C. The predominant soil type is Nitisol, which is dark red brown, and characterized by very strong to moderately acidic soil, and low soil P, specifically around experimental sites with pH of 4.5, and phosphorus level of 1.16 ppm and exchangeable acidity of 2.48 meq/100g of soil (Abush *et al.*, 2017).
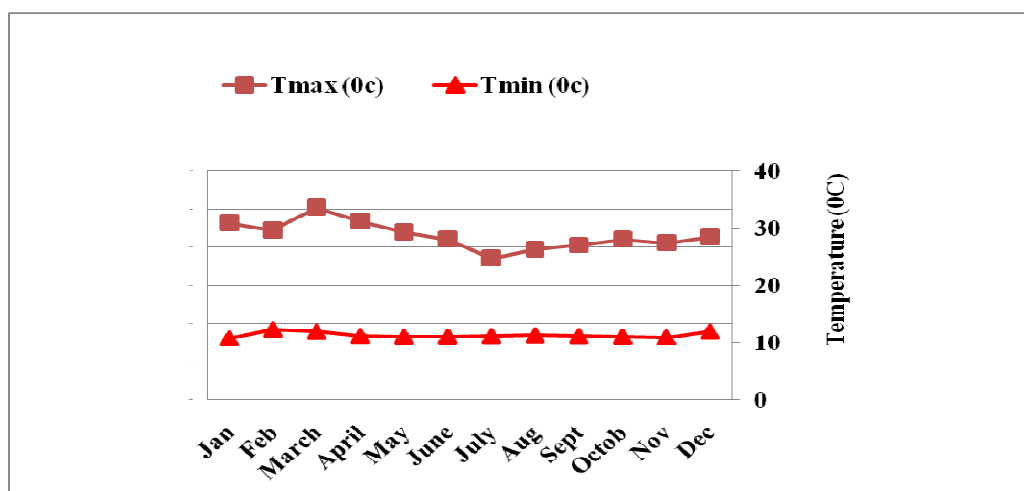
Figure: 1. Mean minimum and maximum temperatures (°C) of Mettu during experimentation in 2017
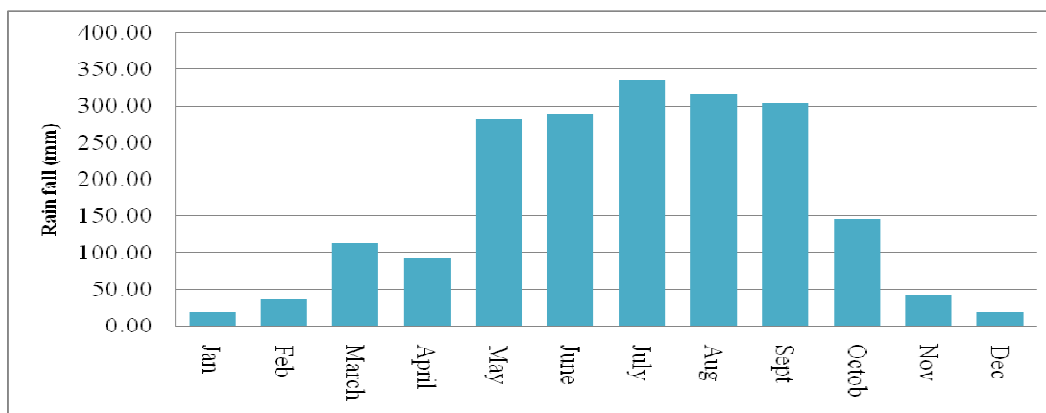

Figure: 2. Monthly total rainfall (mm) of Mettu during experimentation in 2017

Soil sampling, preparation and analysis before planting and after harvesting

Prior to the field experimentation both undisturbed and disturbed samples were collected. The undisturbed samples were taken by core sampler. Fresh weight and an oven dry weight at 105 ^{o}C, and used to determine bulk density (Baruah *et al.*, 1997). The random disturbed composite soil samples (0-15 cm depth) were collected. The composite sample was used for soil physiochemical analysis, and for the determination of lime requirement of the soil. The disturbed soil samples were air dried, sieved to pass through 2 mm sieve, and placed in a labeled plastic bag and transported to Jimma Agricultural Research Center soil laboratory for analysis and   the disturbed composite soil samples were   analyzed for

particle size distribution (soil texture), which was done by Bouyoucos hydrometer method as described by Bouyoucos (1962) that are among the physical soil parameters, while soil exchangeable acidity, exchangeable bases, soil pH, organic carbon (OC), total nitrogen (TN), available phosphorus and cation exchange capacity (CEC) for soil chemical analysis were selected, and all are determined following the standard procedures for each. Similarly, after harvesting, the soil samples were collected main plot-wise from each replication. The amounts of lime applied was determined based on the exchangeable acidity, mass per 0.15m furrow slice and bulk density of the soil (Shoemaker *et al.*, 1961;Van Lierop, 1983), considering   the amount of lime needed to neutralize the acid content (Al + H) of the soil up to the permissible acid saturation level for soybean growth.

Table 1: Physicochemical properties of experimental soil prior planting and after harvesting

Parameters	Before sowing	After harvesting			
		L	C	P	LP
Particle size distribution					
Clay (%)	49.00				
Sand (%)	38.00				
Silt (%)	13.00				
Textural class	Clayey				
pH(H_2O)	4.400	4.73	4.48	4.65	4.90
Exchangeable acidity (cmol(+)/kg)	2.720	1.52	2.41	1.66	1.63
Exchangeable Al (cmol(+)/kg)	1.460	0.93	1.38	0.97	0.92
Organic carbon (%)	2.210	2.45	2.22	2.42	2.56
CEC (cmol (+) kg^{-1})	18.75	21.04	18.89	19.3	21.16
Total N (%)	0.210	0.24	0.22	0.23	0.24
Available P(BrayII)(mg kg^{-1})	2.950	4.39	2.98	5.90	6.89
Exchangeable K (cmol (+) kg^{-1})	0.330	0.67	0.40	0.41	0.69
Exchangeable Ca (cmol(+) kg^{-1})	3.550	5.39	3.81	4.28	5.95
Exchangeable Mg (cmol(+) kg^{-1})	1.380	1.59	1.40	1.42	1.62

Where, P=phosphorus alone, L=lime alone, LP= both lime and phosphorus, C= control

Treatments, Experimental Design and Procedures

The treatments comprised of two factors namely; four soil amendments (control, phosphorus fertilizer alone, lime alone and phosphorus plus lime) and fifteen different soybean genotypes. The treatments were laid out in a split plot design with three replications. The soil amendments were applied as main plots, where as the genotypes were assigned to sub-plot. The different soybean genotypes were identified from various variety trials at JARC including previous soil acidity tolerance screening trials. The lime rate was, 3457.8 kg/ha based on exchangeable acidity of the soil. 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. Phosphorus fertilizer recommended (46 kg P_2O_5 ha^{-1}) (Shahid *et al.,* 2009) was applied at planting and mixed with the soil. Two seeds were sown in rows per hill to maintain between plants and rows spacings of 5 and 60 cm, respectively and then thinned to one plant after seedling establishment. The size of each plot was 2.4 x 4 m (9.6 m^2) and the spacing between replication, sub-blocks and plots were 1.5, 1 and 1 m, respectively. All the recommended cultural practices were used for the management of the experimental crop.

Data Collection and Measurements

Plant height: five plants per plot were randomly selected before harvest and their heights were measured using a tape measure and the mean height was recorded. Shoot dry weight: the shoots of five plants were dried in an oven at 70 ^{O}c for 48 hrs to a constant weight. Dry shoots were then weighted and the mean was recorded. Root volume: the root samples of five plants were collected and immersed carefully in 1000 ml capacity plastic cylinder which is filled up with water. The volume of water displaced by root was recorded. Root dry weight: the roots of five plants were dried at 70 ^{O}c for 48 hrs in an oven to a constant weight and the average root dry weight was recorded. Number of nodule: the count of all the nodules formed by the roots of five plants and averaged as number of nodules per plant. Nodules dry weight: the nodules were dried at 70 ^{O}c for 48 hrs in an oven to a constant weight. The dry nodules were then weighted and the average of nodule dry weight was recorded. Plant stand count: the number of plants from harvestable plot area at harvesting. Number of pods per plant: was counted from five randomly selected at harvest maturity and expressed as an average of each plant. Grain yield was measured by harvesting the crop from the net plot area of the middle two rows. The moisture content of the grain was adjusted to 10% and then converted to kg ha^{-1}. Biomass of 10 randomly selected plants per net plot area was determined by harvesting close to the soil surface at physiological maturity by sun-drying to gain a constant weight. Finally the biomass yield of the selected 10 plants was converted to per hectare.

Statistical Analysis

The data was subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS Institute, 2012) 9.3 Version software using proc GLM procedure. Duncan's multiple range tests was used to separate significantly differing treatment means after treatment effects were

found significant at P ≤ 0.05. Correlation analysis was carried between the parameters to determine magnitude and degree of their relation.

RESULTS AND DISCUSSION

Differences of Genotypes to Lime and Phosphorus for Different Traits

There were highly significant differences ($p \leq 0.01$) among genotypes, amendments and their interactions for all growth, yield and yield components, root and nodulation parameters.

Table 2. Mean squares of amendments, genotypes, and genotype * amendment interaction for different trait at Mettu

Parameters	A	Error (a)	G	G*A	Error(b)	Grand Mean
Plant height (cm)	1225.4**	3.50	1508.67**	13.53**	1.878	49.04
Shoot dry weight(gm)	92.200**	0.068	17.82**	1.872**	0.025	5.857
No of nodule per plant	5523.6**	0.15	675.59**	113.9**	0.88	39.637
Nodule dry weight(gm)	0.1502**	0.00127	0.07211**	0.0036**	0.00058	0.26622
Root dry weight (gm)	1.2581**	0.00106	0.30259**	0.0306**	0.00229	0.8185
Root volume(ml/plant)	13.425**	0.084	3.873**	0.452**	0.185	2.5432
Number of pod per plant	860.89**	0.25	325.78**	36.16**	0.45	25.1861
Biomass(ton/ha)	29.185**	0.5436	9.815**	1.426**	0.21	3.9306
Yield (kg/ha)	3438596.1**	15535.96	999270.4**	13667**	5034.51	1185.45

A= amendments, G= genotypes, G*A= genotype interaction with amendments

Similarly, there were highly significant ($p \leq 0.01$) differences among genotypes for tolerance and susceptibility index based on all growth, yield and yield components, root and nodulation parameters i.e., total nodule number, nodule dry weight, plant height, shoot dry, number of pod per plant, grain yield and above ground biomass (Table 3).

Table 3. Mean squares of genotypes, replication and error for TI, SI and different soybean traits at Mettu in 2017

Parameters	Tolerance index (TI)			Susceptibility index (SI)		
	Rep	G	Error	Rep	G	Error
AGB (tha^{-1})	0.31	1.381**	0.097	0.00374	0.01443**	0.00179
YLD (kg ha^{-1})	0.024	0.472**	0.00498	0.00231	0.0185**	0.00053
NPPP(Nº)	0.02059	1.144**	0.006	0.000027	0.00798**	0.0001
PHT(cm)	0.00566	1.2576**	0.00536	0.00001556	0.000072**	0.000061
SDW(gm)	0.01789	1.9296**	0.006359	0.00012667	0.00916**	0.00011
NN(Nº)	0.0051	1.9548**	0.007	0.00000889	0.01414**	0.000125
RDW(gm)	0.00447	1.316**	0.1402	0.000069	0.006149**	0.00031

Where, ** implies highly significant differences, NPPP= number pod per plant, NSPP= number of seeds per plant, PHT= plant Height, SDW= shoot dry weight, RFW= root fresh weight, YLD= yield, NN= number of nodules per plant, AGB= above ground biomass G= genotypes, biomass, TI=tolerance index, SI= susceptibility index.

Differences of genotypes to lime and phosphorus for growth parameters

Genotype, PI567046A showed the highest plant height of 84.2cm, 83.74cm and 83.2cm on P alone, lime alone and P with lime combined main effects respectively (Table 4). The performance of most of the genotypes on lime and P amended soil showed taller plant height, compared to their performance on lime and P amended, separately. This might indicate that the most of the genotypes are responsive to the combined amendment of P with lime, which is also evidenced by the significantly highest performance of P with lime amendment, over P alone, lime alone and the control (Table 4). Mesfin *et al.* (2014) reported, varietal difference for plant height, though their result was based on study made on only two varieties, in

which Hawassa Duma variety had taller plant height than Omo-95 under unlimed and limed acid soil at the rate of 20 kg P ha^{-1} with lime. Genotypes responded to phosphorus and liming amendment, which might be due to the effect of P together with lime, has a very important role, which increases the availability of applied P, and also helps in raising pH of the soil and reduces the effect of acidity on the performance of the crop. However, P deficiency causes immediate disturbances in metabolism and suffered to stunted growth. The results are similar with the results of Kisinyo et al. (2016) who reported that a growth of plant is increased on acid soil in response to the application of P with lime.

Table 4. The interaction effect of amendments and genotypes on plant height under lime and Phosphorus treated and untreated acid soil condition during 2017/18 main cropping season

Genotypes	Plant height (cm)				PHT- RP (%)		
	L	C	P	LP	L	P	LP
PI567046A	83.74^a	73.27^b	84.20^a	83.20^a	12.51	12.98	11.94
HAWASSA-04	55.40^{f-j}	50.34^{k-p}	58.14^{d-g}	62.67^c	9.13	13.42	19.67
JM-PR142/H3-15-SB	54.72^{g-j}	47.00^{p-v}	56.74^{e-i}	59.67^{cde}	14.10	17.17	21.23
BRS268	53.80^{h-l}	48.00^{o-u}	59.40^{cde}	57.60^{e-h}	10.78	19.19	16.67
JM-CLK/CRFD-15-SA	48.93^{n-s}	42.73^{ABw-z}	46.00^{q-x}	53.93^{h-k}	12.67	7.10	20.78
JM-CLK/G99-15-SC	48.80^{n-t}	43.13^{Av-z}	48.06^{o-u}	54.33^{g-j}	11.61	10.26	20.61
JM-H3/SCS-15-SG	48.94^{n-s}	44.87^{t-y}	59.20^{c-e}	61.60^{cd}	8.32	24.21	27.16
JMALM/PR142-15-SC	46.23^{q-w}	44.20^{u-z}	52.45^{j-n}	53.53^{i-m}	4.39	15.73	17.43
JM-ALM/H3-15-SC-1	45.87^{r-x}	41.54^{ABCyz}	49.74^{m-r}	53.87^{h-k}	9.43	16.49	22.88
SCS-1	44.84^{t-y}	39.00^{BCD}	49.20^{n-s}	54.33^{g-j}	13.02	20.73	28.22
JM-CLK/G99-15-SB	43.08^{Av-z}	40.70^{zABCD}	45.30^{s-y}	49.87^{l-q}	5.52	10.15	18.38
JM-HAR/DAV-15-SA	38.60^{CD}	33.60^{FG}	42.06^{ABCxyz}	51.94^{j-o}	12.95	20.13	35.31
JM-DAV/PR142-15-SA	37.34^{DEF}	34.40^{EFG}	39.80^{BADC}	44.50^{u-z}	7.87	13.57	22.70
PI423958	32.26^{GH}	26.20^I	38.30^{CDE}	41.30^{ABCyz}	18.8	31.59	36.56
H-7	32.00^{GH}	29.60^{HI}	38.40^{CD}	40.07^{ABCD}	7.50	22.92	26.12
Mean	47.63^c	42.56^d	51.12^b	54.82^a	10.6	17.0	23.0
CV(a)= 3.8		CV(b): 2.79					

Where, L= Lime treated alone, P= Phosphorus treated alone, PHT= plant height, RP= reduction percentage, LP= lime and phosphorus treated, CV= Co-efficient of variation, C= Control, Means with capital letters are the letters come backs after Z, Note: Means with the same letters are statistically not significant (p > 0.05) different from each other.

The highest shoot dry weights (9.95 and 9.89g) were recorded on the variety HAWASSA-04 on lime and P combined, and only P amended soil, respectively. Genotype SCS-1 produced the lowest shoot dry weight of 1.97g on the control main plot (Table 5). This is because of shoot dry weight is the result of shoot growth and development, including epicotyl and hypocotyl lengths, which is supported by the earlier works of Liang et al. (2013), who reported considerable differences among two soybean genotypes, in which shoot dry weight of HN89 genotype was 100 and 75% greater than that of HN112 genotype at low (0kg/ha p) and high (30kg/ha P) levels, respectively.

The poor performance of plants for shoot dry on the control main plot might be due to the deficiency of Mg, P and Ca, which might have played important role in the plants i.e., Mg is an important component of chlorophyll, which helps in capturing energy from the sun for growth and development. Genotype PI567046A showed high percentage decrease (65%) for shoot dry weight under control main plot, whereas genotype BRS268 showed low percentage decrease (-0.34 %), on control plot relative with P and lime and lime alone respectively. In line with this result Foy (1993) reported that genotypes: Salute216, Davis, and Santa Rosa grown at low P stunted growth and cupped leaves and contained low concentrations of Ca and P in their leaf than, when grown under applied phosphorus.

Table 5. The interaction effect of amendments and genotypes on Shoot dry weight of soybean genotypes under acid soil condition in field at Metu during 2017/18 cropping season

Genotypes	Shoot dry weight(g)				SDW- RP (%)		
	L	C	P	LP	L	P	LP
HAWASSA-04	7.04[def]	5.83[jklm]	9.89[a]	9.95[a]	17.26	41.05	41.41
JM-HAR/DAV-15-SA	4.83[pqr]	4.97[opq]	6.16[ghijk]	9.22[b]	-2.90	19.36	46.1
PI423958	6.48[ghi]	3.69[u]	7.06[def]	8.64[c]	43.06	47.69	57.26
H-7	5.18[pon]	4.02[tu]	4.54[qrst]	8.52[c]	22.28	11.44	52.75
JM-PR142/H3-15-SB	5.40[mno]	3.99[tu]	7.18[de]	8.30[c]	26.11	44.48	51.93
JM-ALM/PR142-15-SC	6.16[ghijk]	5.45[mno]	8.14[c]	8.16[c]	11.57	33.07	33.24
JM-H3/SCS-15-SG	5.58[lmn]	4.38[rst]	7.32[d]	7.57[d]	21.40	40.05	42.11
JM-CLK/G99-15-SB	7.57[d]	4.38[rst]	6.14[hijkl]	7.35[d]	42.19	28.63	40.41
JM-CLK/G99-15-SC	5.72[klmn]	4.81[pqr]	6.70[efg]	7.56[d]	15.91	28.24	36.38
BRS268	5.93[ijklm]	5.95[ijklm]	7.39[d]	7.52[d]	-0.34	19.49	20.88
PI567046A	6.32[ghij]	2.29[w]	5.91[jklm]	6.62[fgh]	63.77	61.25	65.42
JM-ALM/H3-15-SC-1	2.94[v]	2.38[w]	4.59[qrs]	5.02[opq]	19.05	48.15	52.62
JM-CLK/CRFD-15-SA	4.34[rst]	2.92[v]	3.63[u]	5.62[klmn]	32.72	19.56	48.04
SCS-1	3.60[u]	1.97[w]	4.12[stu]	5.43[mno]	45.28	52.14	63.72
JM-DAV/PR142-15-SA	4.76[pqr]	4.78[pqr]	6.08[hijkl]	7.29[d]	-0.40	21.38	34.43
Mean	**5.45[c]**	**4.123[d]**	**6.236[b]**	**7.519[a]**	23.8	34.4	45.8
	CV(b) : 2.68		**CV(a)=4.45**				

Where, L= Lime treated alone, P= Phosphorus treated alone, LP= lime and phosphorus treated, SDW= shoot dry weight, RP= reduction percentage, CV=coefficient of variation, C= Control, Note: Means with the same letters are statistically not significant (p>0.05) different from each other

Differences of genotypes to lime and phosphorus for nodule and root parameters

The highest number of nodules per plant (79.4) was obtained from genotype PI423958 under combined application of lime and P, while, the lowest total number of nodules per plant (15.67) was recorded at the control soil condition from a genotype SCS-1 (Table 6) which showed about 406.7% difference with the top genotype. The high performance of genotype PI423958 for almost all the nodulation characteristics was shown in (Tables 6). However, the performance of genotype PI423958 under the control soil condition was very low relative to other genotypes. This imply that this genotype is more of responsive than tolerant in terms of nodule number per plant, which implies its sensitivity to acid soils. Moharram et al. (1994) reported varietal difference in the nodulation and N- fixation characters, in which variety Clark gave better response though their result was based on only two varieties.

The presence of significant interaction of genotypes and amendment for total number of nodules per plant indicates the differential response of genotypes to lime and P application, thus implying the possibility of selecting genotypes that perform, exceptionally to low P or alumunium toxicity and high P conditions, which is supported by the earlier works of Abush et al. (2017) who reported that, two soybean genotypes i.e., H3 and PR-142

(26) showed the highest number of nodules per plant at 100 kg ha^{-1}P, while, the lowest number of nodules per plant was showed by Essex-1 genotype at 0 kg ha^{-1} p among the other genotypes. The authors also reported that the decreased in nodulation parameters i.e. number of nodule, nodule fresh and dry weight of soybean genotypes when planted on P deficient soil, and variation among genotypes i.e., genotype H3 showed high decrements for nodule numbers.

Genotype PI423958 gave the highest nodule dry weight per plant of 0.5g and 0.48 gm under the combined application of P with lime, and P treated alone main effects, respectively. The lowest nodule dry weight per plant (0.07g) was recorded from a genotype SCS-1 on the control main plot, which showed more than 614.28% nodule dry weight difference with the highest genotype (Table 6). Genotype SCS-1 showed high decrease percentage of 67.1% for nodule dry weight and genotype BRS268 showed the lowest decrease percentage of -3.1% (Table 6). The nodulation characteristics of soybean are dependent on the nutrient availability in the soil, such as Ca and P fertilization and the types of soybean genotypes (Moharram et al., 1994). Correa et al. (2001) reported that alfalfa (Medicago sativa. L.) and Lotus (Glaber mill) varied in their nodulation and nitrogen fixation ability on acid soil condition or at pH 4.0, due to variation in host tolerance to low pH. Similarly, authors also reported that low pH reduced nodule mass by 48% and nodule quality by 29%.

Table 6. The interaction effect of amendments and genotypes on number of nodule per plant and Nodule dry weight per plant of soybean grown under acid soil condition in field at Mettu during 2017/18 cropping season

Genotypes	Number of Nodule per plant(No)				NN-RP (%)			Nodule dry weight per plant (g)				NDW-RP (%)		
	L	C	P	LP	L	P	LP	L	C	P	LP	L	P	LP
PI423958	55.27^f	35.07^r	64.93^c	79.40^a	36.5	46.0	55.8	0.37^{c-h}	0.257^{m-w}	0.48^{ab}	0.50^a	30.5	46.5	48.6
HAWASSA-04	39.07^o	33.60st	52.20^j	61.07^d	13.9	35.6	44.9	0.33^{e-l}	0.27^{k-v}	0.42^{bcd}	0.42^{bcd}	18.2	35.7	35.7
JM-CLK/G99-15-SB	37.33^{pq}	23.33^B	33.33^t	50.13^j	37.5	30.0	53.4	0.32^{f-n}	0.17^{ABCDyz}	0.28^{j-u}	0.35^{d-j}	46.9	39.3	51.4
JM-PR142/H3-15-SB	39.40^o	32.267^u	50.067^j	73.33^b	18.1	35.5	56.0	0.26^{m-w}	0.23^{p-z}	0.36^{d-i}	0.44^{bac}	11.5	36.1	47.7
JM-H3/SCS-15-SG	35.20^r	26.20^z	42.33^m	42.60^m	25.5	38.1	38.5	0.25^{m-w}	0.21^{ABv-z}	0.31^{f-o}	0.34^{e-k}	16.0	32.3	38.2
PI567046A	32.467^u	20.00^C	41.07^n	56.87^e	38.4	51.3	64.8	0.25^{m-w}	0.14^{BCDE}	0.32^{f-o}	0.32^{f-m}	44.0	56.3	56.3
H-7	39.00^o	34.13st	38.00^p	50.60^j	12.4	10.1	32.5	0.24^{o-y}	0.23^{r-z}	0.24^{n-x}	0.30^{h-s}	4.2	4.2	23.3
JM-ALM/PR142-15-SC	37.33^{pq}	30.87^{v-x}	54.33^g	53.47^h	17.3	43.1	42.2	0.22^{Au-z}	0.22^{Au-z}	0.37^{c-i}	0.37^{c-g}	0.0	40.5	40.5
JM-HAR/DAV-15-SA	31.23^{vw}	30.80^{wx}	47.33^k	52.73^{hi}	1.39	34.9	41.5	0.30^{g-r}	0.30^{g-p}	0.38^{cdef}	0.39^{cde}	0.0	21.1	23.1
JM-CLK/G99-15-SC	30.33^x	23.20^B	45.53^l	48.00^k	23.5	49.0	51.6	0.21^{BAv-z}	0.20^{ABCv-z}	0.31^{f-n}	0.32^{f-m}	4.8	35.5	37.5
JM-DAV/PR142-15-SA	32.40^u	31.67^{uv}	35.87^r	61.00^d	2.26	11.7	48.0	0.22^{At-z}	0.23^{r-z}	0.29^{i-t}	0.30^{g-q}	-4.5	20.7	23.3
BRS268	31.23^{vw}	31.27^{vw}	35.40^r	35.60^r	-0.1	11.6	12.1	0.23^{s-z}	0.23^{t-z}	0.25^{m-w}	0.26^{l-w}	0.0	8.0	11.5
JM-CLK/CRFD-15-SA	37.13^q	22.67^B	31.40^{vw}	46.27^l	38.9	27.8	51.0	0.17^{xyzABD}	0.11^{DE}	0.17^{x-zABD}	0.19^{ABCw-z}	35.3	35.3	42.1
JM-ALM/H3-15-SC-1	34.267^s	17.60^D	30.67^{wx}	35.87^r	48.6	42.6	50.9	0.13^{CDE}	0.10^{DE}	0.15^{ABCD}	0.16^{zABCD}	23.1	33.3	37.5
SCS-1	24.20^A	15.67^E	28.67^y	55.93^f	35.2	45.3	71.9	0.11^{DE}	0.07^E	0.15^{ABCD}	0.21^{ABu-z}	36.4	53.3	66.7
Mean	**35.725^c**	**27.22^d**	**42.076^b**	**53.52^a**	**23.3**	**34.2**	**47.7**	**0.241^c**	**0.198^d**	**0.299^b**	**0.326^a**	**17.8**	**33.2**	**38.9**
	CV(b)=2.37							CV(a)=13.38		CV(b)= 9.03				

Where, L= Lime treated only, P= Phosphorus treated only, LP= both lime and phosphorus treated, CV= coefficient of variation, NN= number of nodule, NDW= nodule dry weight, C= Control, RP= reduction percentage, Means with capital letters are the letters come backs after Z, Note: Means with the same letters are statistically not significant (p>0.05) different from each other.

Genotypes:JM-PR142/H3-15-SB, JM-ALM/PR142-15-SC, PI567046A, BRS268, JM-ALM/H3-15-SC-1, PI423958, and HAWASSA-04 variety, gave the highest root volume of 4, 4, 3.73, 3.67, 3.67, 3.53, and 3.40 ml/plant respectively under combine application of P with lime and genotypes: JM-PR142/H3-15-SB and JM-ALM/PR142-15-SC produced 4ml/plant under P alone, while the lowest root volume (1 ml/plant) was produced by genotype JM-CLK/G99-15-SB in the control and P treated alone main plots. This indicates the differential response of genotypes for lime and P treated and untreated acid soil conditions, thus implying the possibility of selecting genotypes that perform, exceptionally to optimum lime and P treated and untreated soil conditions, which is supported by earlier work of Abush et al. (2017) who reported differential response of soybean genotypes to root and nodulation characteristic in which, genotypes AA-42-52, PR-

142 (26), IAC6, PR-143(14), and IAC11 produced the highest root volume among the tested genotypes.

Root hair length and density are affected by soil acidity (Haling et al., 2011), which led to root volume and weight alteration. Root hairs are effective in extending the width of the P depletion zone around the root through increasing the volume of the soil explored for phosphorus. Some plant species/genotypes are adapted to produce longer and more root hairs under P deficient conditions. According to Eticha and Schenk (2001), genetic variation in the length and density of root hairs is essential for the absorption of immobile nutrients, such as P and K, and such traits contribute to considerable yield improvement on low fertility or acidic soils. Thus, plant species or genotypes of the same species with different root hair length and different root hair number may exhibit different P uptake efficiency.

Table 7. Interaction effect of different amendments and genotypes on Root volume (ml) of soybean genotypes under acid soil condition in field at Metu

Genotypes	Root volume (ml)				RV-RP		
	L	C	P	LP	L	P	LP
JM-PR142/H3-15-SB	2.77^{f-i}	2.33^{i-l}	4.00^{a}	4.00^{a}	15.78	41.68	41.68
JM-ALM/PR142-15-SC	3.67^{bac}	2.77^{f-i}	4.00^{a}	4.00^{a}	24.67	30.75	30.75
PI567046A	2.33^{kij}	1.67^{omn}	3.33^{b-e}	3.73^{ba}	28.12	49.68	55.04
BRS268	2.33^{i-l}	2.33^{i-l}	3.27^{b-f}	3.67^{bac}	0.00	28.65	36.55
JM-ALM/H3-15-SC-1	2.4^{h-k}	1.67^{omn}	3.20^{b-f}	3.67^{bac}	30.13	47.59	54.39
HAWASSA-04	2.33^{kij}	2.33^{i-l}	3.67^{bac}	3.53^{a-d}	0.00	36.55	33.97
PI423958	2.33^{kij}	1.33^{onp}	3.33^{b-e}	3.40^{a-e}	42.86	60.01	60.79
JM-CLK/CRFD-15-SA	2.53^{g-j}	2.33^{kij}	2.77^{f-i}	3.33^{b-e}	7.900	15.78	30.00
JM-H3/SCS-15-SG	2.33^{kij}	2.00^{j-m}	3.00^{d-h}	3.20^{b-f}	14.27	33.33	37.5
SCS-1	2.77^{f-i}	1.53^{m-p}	3.00^{d-h}	3.06^{c-g}	44.66	48.90	49.90
JM-CLK/G99-15-SC	2.00^{j-m}	1.20^{op}	2.40^{h-k}	2.80^{e-i}	40.00	50.00	57.14
JM-HAR/DAV-15-SA	2.00^{j-m}	2.00^{j-m}	2.00^{j-m}	2.53^{g-j}	0.00	0.00	21.04
JM-DAV/PR142-15-SA	1.87^{k-n}	1.87^{k-n}	2.00^{j-m}	2.33^{i-l}	0.00	6.150	19.55
H-7	2.00^{j-m}	1.67^{omn}	1.33^{onp}	2.00^{j-m}	16.15	-25.8	16.15
JM-CLK/G99-15-SB	1.67^{omn}	1.33^{onp}	1.00^{p}	1.73^{l-o}	20.51	-33.3	23.08
Mean	**2.34^{c}**	**1.88^{d}**	**2.82^{b}**	**3.13^{a}**	**19.00**	**26.0**	**37.84**
	CV(a)= 11.2		**CV(b) : 16.92**				

Where, L= Lime treated only, P= Phosphorus treated only, LP= both lime and phosphorus treated, RV= root volume, NFW= nodule fresh weight, RP= reduction percentage, CV= coefficient of variation, C= Control, Note: Means with the same letters are statistically not significant (p>0.05) different from each other.

The highest root dry weight (1.28 and 1.26 g/plant) was produced by genotypes JM-PR142/H3-15-SB and JM-ALM/PR142-15-SC , respectively under P treated alone condition; whereas the lowest root dry weight (0.427, 0.43, 0.433,0.44 and 0.47 g/pant) was recorded under the control plot from genotypes: PI423958, SCS-1, PI567046A, JM-CLK/G99-15-SB and JM-CLK/G99-15-SC, respectively. The genotype that produced the highest root dry weight showed more than 199.8% increase over the lowest genotype (Table 8). Genotypes: JM-ALM/PR142-15-SC and BRS268 produced the highest root dry weight under the control soil condition, and indicating these genotypes might be among acidic soil tolerant genotypes (Table 8). The performance of most genotypes on combined P with lime amendment showed higher performance compared to their performance on separately lime and P amended soil. This indicated that genotypes are responded to P and lime, which might be due to phosphorus fertilizers enhance root proliferation, and consequently improving the P uptake capacity of plants which facilitate root growth, and then increased root diameter or root thickness of the genotypes, and root dry weight is the result of root growth and development. Root hair length and density is affected by soil acidity (Haling et al., 2011) led to root dry weight alteration. Kuswantoro (2015) also reported that MLGG 0064 genotype showed the highest root dry weight under the neutral (pH 7), while the lowest was shown by genotype MLGG 0377 in Mn toxicity, which shows varietal difference for acid soil adaptation.

Table 8. The interaction effect of amendments and genotypes on Root dry weight of soybean grown under acid soil in field at Mettu during 2017/18 cropping season

Genotypes	Root dry weight (g)				RDW-RP (%)		
	L	C	P	LP	L	P	LP
JM-PR142/H3-15-SB	0.79[s-v]	0.74[u-x]	1.28[a]	1.25[ab]	6.30	42.2	40.8
JM-ALM/PR142-15-SC	0.94[i-l]	0.87[l-q]	1.26[a]	1.25[ab]	7.40	31.0	30.4
BRS268	0.84[o-s]	0.83[p-s]	1.19[bc]	1.19[bc]	1.20	30.3	30.3
JM-CLK/CRFD-15-SA	0.89[l-p]	0.75[t-w]	0.99[f-i]	1.18[c]	15.7	24.2	36.4
JM-ALM/H3-15-SC-1	0.71[wxy]	0.65[zyA]	1.08[ed]	1.10[d]	8.50	39.8	40.9
HAWASSA-04	0.81[qrst]	0.81[q-t]	1.06[ed]	1.06[def]	0.00	23.6	23.6
SCS-1	0.80[rstu]	0.43[D]	0.96[h-k]	1.05[d-g]	46.3	55.2	59.0
JM-H3/SCS-15-SG	0.71[wxy]	0.63[zAB]	0.98[g-j]	1.01[e-h]	11.3	35.7	37.6
PI567046A	0.75[t-x]	0.43[D]	0.90[k-o]	0.92[j-m]	42.7	52.2	53.3
JM-HAR/DAV-15-SA	0.55[C]	0.55[C]	0.85[m-s]	0.91[k-n]	0.00	35.3	39.6
PI423958	0.59[ABC]	0.43[D]	0.88[l-p]	0.86[m-r]	27.1	51.1	50.0
H-7	0.63[zAB]	0.58[ABC]	0.54[C]	0.84[n-s]	7.90	-7.4	31.0
JM-DAV/PR142-15-SA	0.74[xwv]	0.72[xw]	0.68[xzy]	0.75[t-w]	2.70	-5.9	4.00
JM-CLK/G99-15-SC	0.65[zyA]	0.47[D]	0.72[xw]	0.72[vwx]	27.7	34.7	34.7
JM-CLK/G99-15-SB	0.64[zA]	0.44[D]	0.56[BC]	0.58[ABC]	31.3	21.4	24.1
Mean	**0.74[c]**	**0.63[d]**	**0.93[b]**	**0.98[a]**	**15.7**	**30.9**	**35.7**
	CV(a)= 4.23		**CV(b): 5.71**				

Where, L= Lime alone, P= Phosphorus alone, LP= Lime and Phosphorus, CV= Coefficient of variation, RDW= root dry weight, RP= reduction percentage, C= Control, Means with capital letters are the letters come backs after Z, Note: Means with the same letters are statistically not significant (p>0.05) different from each other

Differences of genotypes to lime and phosphorus for yield and yield components

Genotype PI567046A gave higher number of pods (48) per plant under combined application of P with lime, while, the lowest number of pods per plant (9.67) was produced by genotype PI4239589 under the control main plots (Table 9). Genotype PI4239589 showed highest decrease (62.71%) of number of pods per plant; whereas genotype JM-ALM/PR142-15-SC showed lowest decrease of -5.2% under control soil conditions, which indicated that the tolerance and susceptibility of these genotypes, and which might also due to the performance variation among the tested genotypes for number of pods. Habtamu (2017)

reported that genotype ALB207 gave the highest number of pods per plant (9.42) on lime treated plots than Roba genotype which produced low number of pods per plant (4.83) on lime untreated plots. Mesfin et al. (2014) also reported that the highest number of pods per plant (12.9 and 11) for Hawassa Dume and Omo-95 variety, in response to combined application of 0 ton ha^{-1} lime and 30 kg ha^{-1} P_2O_5, 0.4 t ha^{-1} lime and 20 kg ha^{-1} P_2O_5, respectively. The applied lime and P enhanced vegetative growth, thereby, enabling the plant to bear higher number of pods than the untreated soil, and neutralizing soil acidity by lime, which in turn increases availability of P for plant uptake, through reduction in its fixation on acid soils (Kisinyo et al., 2016).

Table 9. The interaction effect of amendments and genotypes on number of pod per plant under acid soil condition at Metu during 2017/18 main cropping season

Genotypes	Number pod per plant(No)				NP-RP (%)		
	L	C	P	LP	L	P	LP
PI567046A	47.07^b	26.60^{kl}	33.73^e	48.00^a	43.4	21.1	44.58
BRS268	30.34^g	27.60^{jk}	38.14^c	38.00^c	9.03	27.6	27.37
HAWASSA-04	29.27^h	22.94^{pq}	26.67^{kl}	34.00^e	21.6	13.9	32.53
JM-CLK/G99-15-SB	22.94^{pq}	21.80^{rs}	23.14^{po}	25.00^{mn}	4.97	5.79	12.80
JM-CLK/G99-15-SC	22.54^{pqr}	21.94^{qrs}	26.20^l	35.27^d	2.66	16.2	37.79
JM-CLK/CRFD-15-SA	22.54^{pqr}	18.07^{Az}	19.27^{xy}	28.00^{ij}	19.8	6.23	35.48
JM-PR142/H3-15-SB	21.54^{rst}	19.47^{wxy}	26.67^{kl}	31.47^f	9.63	27.0	38.14
H-7	21.34^{stu}	18.00^{Az}	25.90^{lm}	28.53^{hij}	15.6	30.5	36.91
JM-ALM/H3-15-SC-1	21.27^{stuv}	18.93^{yz}	26.80^{kl}	29.00^{hi}	10.9	29.3	34.71
JM-H3/SCS-15-SG	20.54^{tuv}	20.47^{uvw}	22.50^{pqr}	28.53^{hij}	0.36	9.04	28.26
JM-ALM/PR142-15-SC	20.27^{vwx}	21.34^{stu}	24.00^{no}	24.14^{no}	-5.2	11.0	11.60
JM-HAR/DAV-15-SA	19.27^{xy}	17.40^{AB}	24.90^n	36.14^d	9.69	30.1	51.85
JM-DAV/PR142-15-SA	24.33^n	24.80^n	26.07^l	26.20^l	-1.9	4.87	5.340
SCS-1	17.93^{Az}	16.53^B	22.50^{pqr}	22.87^{pq}	7.81	26.5	27.71
PI423958	13.33^C	9.670^D	23.27^{op}	25.93^{lm}	27.4	58.4	62.71
Mean	$\mathbf{23.63^c}$	$\mathbf{20.37^d}$	$\mathbf{25.98^b}$	$\mathbf{30.77^a}$	**11.7**	**21.2**	**32.5**
CV(a)= 2.0		**CV(b) = 2.67**					

Where, L= Lime alone, P= Phosphorus alone, LP= lime and phosphorus treated, NP= number of pod, NS= number of seed, RP= reduction percentage, CV= coefficient of variation, C= Control, RP: reduction percentage, Note: Means with capital letters are the letters come backs after Z, Means with the same letters are statistically not significant (p>0.05) different from each other.

The highest biomass (7.05tha^{-1}and 7.02t ha^{-1}) was obtained from PI567046A genotype under the combined application of lime with P, and lime treated alone, respectively (Table 10);

While the lowest biomass (1.43t ha^{-1}) was recorded on genotype PI423958 under the control main plots (Table 10). The performance of most genotypes under lime with P amendment conditions showed high increments compared to their performance on lime and P amended, separately. This indicated that the response of genotypes across amendments had significant effect on biomass production. Liang *et al.* (2013) reported that the difference in biomass production among two soybean genotypes, in which P-efficient genotype (HN89) adapted better to the acidic soil than the P-inefficient genotype (HN112), and showed greater biomass, especially under applied phosphorus.

Liming and P improved P supply to the soil or an improved ability of the plant to absorb P and enhanced the vegetative growth of soybean genotypes, resulted in increased biomass. Genotype PI423958 showed the highest decrease of 66.22%, while genotype JM-H3/SCS-15-SG showed low decrease of -1.3% for biomass under control main plot. Temesgen *et al.* (2017) reported that barley biomass was reduced in control plots by 38.2%

compared with P treated plots. The authors also reported the highest biomass were recorded on limed soil with 2.2 t ha^{-1} and 30 kg P ha^{-1} than separate application of lime and phosphorus.

HAWASSA-04 variety and Genotypes: PI567046A and PI423958 with respective mean grain yield of 2047.2, 2050, and 1981.6 kg ha^{-1} under the combined amendment of P with lime and genotype PI567046A with respective mean grain yield of 1534.5 and 1943.9 kg ha^{-1} under P alone and lime alone soils, respectively, and HAWASSA-04 variety with mean grain yield of 2120 kg ha^{-1} under lime alone soils gave the highest grain yield (Table 10). HAWASSA-04 variety and genotype BRS268 produced the highest grain yield at the control soils, and were among the top performing genotypes across different soil amendments. In this study, the variable response of genotypes for applied lime and P has been observed, which indicates the presence of difference among the tested genotypes for yield and yield components in response to the amendments. Nigussie (2012) reported the difference in yield performance among different bean genotypes. The positive response of these genotypes to the applied lime and P might be due to the probability of obtaining the available P from decomposed OM by

Table 10. The interaction effect of amendments and genotypes on above ground biomass (ton/ha) and yield (kg/ha) of soybean genotypes under acid soil condition in field at Metu during 2017/18 main cropping season

Genotypes	YLD (kg)/ha				YLD- RP (%)			AGB ton/ha				AGB-RP (%)		
	L	C	P	LP	L	P	LP	L	C	P	LP	L	P	LP
HAWASSA-04	1576.8^{cde}	1553.1^{de}	2120.0^{a}	2047.2^{ab}	1.50	26.74	24.1	5.06^{b-h}	4.20^{g-p}	5.90^{a-f}	5.97^{a-e}	17.0	28.85	29.61
PI567046A	1943.9^{ab}	1069.9^{k-q}	1534.5^{def}	2050.0^{ab}	44.96	30.28	47.8	7.02^{a}	3.23^{k-v}	5.18^{b-h}	7.05^{a}	54.0	37.68	54.18
PI423958	682.80^{t-y}	528.20^{xy}	1552.7^{de}	1981.6^{ab}	22.64	65.98	73.3	1.86^{vw}	1.43^{w}	4.23^{g-o}	4.23^{g-o}	23.4	66.22	66.22
JMALM/PR142-15-SC	1214.5^{g-m}	1121.3^{i-p}	1615.9^{cd}	1832.6^{bc}	7.67	30.61	38.8	4.01^{h-r}	3.96^{h-q}	4.54^{d-k}	4.45^{e-m}	1.25	12.84	11.01
JM-HAR/DAV-15-SA	737.50^{s-y}	691.00^{t-y}	1287.6^{f-l}	1830.4^{bc}	6.31	46.34	62.2	2.35^{s-w}	2.23^{uvw}	3.89^{h-r}	6.17^{abc}	5.11	42.77	63.90
JM-PR142/H3-15-SB	1328.3^{e-j}	1027.2^{m-r}	1475.8^{d-g}	1641.2^{cd}	22.67	30.40	37.4	4.23^{g-o}	3.58^{i-u}	5.59^{a-g}	6.24^{abc}	15.5	36.03	42.69
H-7	772.50^{r-y}	821.80^{q-w}	1173.3^{h-n}	1483.2^{def}	-6.38	29.96	44.5	2.43^{s-w}	2.27^{tuvw}	3.90^{h-r}	4.06^{h-q}	6.84	41.84	44.13
BRS268	1143.5^{i-o}	1319.8^{e-k}	1473.3^{d-g}	1321.9^{e-k}	-15.4	10.42	0.16	4.01^{h-r}	3.79^{h-s}	6.36^{ab}	6.08^{a-d}	5.41	40.14	37.68
JM-H3/SCS-15-SG	956.50^{n-s}	1096.5^{i-p}	1344.5^{e-i}	1428.7^{d-h}	-14.6	18.45	23.2	3.52^{i-u}	3.56^{i-u}	4.26^{g-o}	4.83^{b-i}	-1.3	16.33	26.15
JM-CLK/CRFD-15-SA	935.00^{n-t}	643.50^{v-y}	898.40^{o-v}	1408.4^{d-h}	31.18	28.37	54.3	3.43^{i-u}	2.89^{o-w}	3.05^{l-v}	4.45^{e-l}	15.7	5.430	35.10
JM-ALM/H3-15-SC-1	653.20^{u-y}	637.50^{v-y}	1130.4^{i-p}	1215.5^{g-m}	2.40	43.60	47.5	3.06^{l-v}	2.73^{q-zA}	4.30^{g-o}	4.35^{f-n}	10.7	36.56	37.29
JM-CLK/G99-15-SC	783.80^{r-x}	818.20^{q-w}	1180.6^{h-n}	1123.0^{i-p}	-4.39	30.70	27.1	3.51^{i-u}	3.52^{i-u}	3.78^{h-s}	4.68^{c-j}	-0.3	6.880	24.78
SCS-1	619.00^{wxy}	510.50^{y}	967.40^{m-s}	1174.3^{h-n}	17.53	47.23	56.5	2.58^{r-w}	2.36^{s-w}	3.50^{i-u}	3.71^{h-t}	8.41	32.54	36.41
JM-CLK/G99-15-SB	1076.2^{j-q}	757.00^{s-y}	906.10^{o-u}	1121.1^{i-p}	29.66	16.46	32.4	2.79^{p-w}	2.65^{Ar-z}	3.36^{j-v}	3.13^{l-v}	4.91	21.04	15.40
JM-DAV/PR142-15-SA	934.70^{n-t}	915.40^{o-t}	878.10^{p-w}	1060.0^{l-q}	2.06	-4.25	13.6	2.99^{n-v}	3.07^{l-v}	3.04^{m-v}	3.09^{l-v}	-2.5	-0.89	0.650
Mean	**1023.87^{c}**	**900.73^{d}**	**1302.59^{b}**	**1514.61^{a}**	**8.64**	**26.0**	**34.5**	**3.52^{c}**	**3.03^{d}**	**4.32^{b}**	**4.83^{a}**	**11.0**	**26.7**	**31.6**
	CV(a)= 10.51		**CV (b)= 6.24**					**CV(a)=18.75**		**CV(b)=11.68**				

Where, L= Lime treated alone, P= Phosphorus treated alone, LP= Lime and phosphorus treated, YLD = yield, AGB= above ground biomass, CV= Coefficient of variation, C= Control, RP= reduction percentage, Note: Means with the same letters are statistically not significant (p>0.05) different from each other.

Table 11: Average values of Grain yield, Biomass (BM), plant height (PHT), number of pod per plant (NPPP), shoot dry weight(SDW) and number of nodule(NN) of soybean genotypes grown under amended and unamended acid soils at Mettu.

Main Plot Treatments	GY	NPPP	PHT	SDW	RDW	NN	BM
Control (no amendment)	900.73^{d}	20.37^{d}	42.56^{d}	4.12^{d}	0.63^{d}	27.22^{d}	3.03^{d}
Lime alone	1023.87^{c}	23.63^{c}	47.63^{c}	5.45^{c}	0.74^{c}	35.72^{c}	3.52^{c}
Phosphorus alone	1302.59^{b}	25.98^{b}	51.12^{b}	6.24^{b}	0.93^{b}	42.07^{b}	4.32^{b}
Both lime and phosphorus	1514.61^{a}	30.77^{a}	54.82^{a}	7.52^{a}	0.98^{a}	53.52^{a}	4.83^{a}
CV	**10.51**	**2.0**	**3.8**	**4.45**	**5.71**	**2.37**	**18.75**
Mean	**1185.4**	**25.18**	**49.04**	**5.86**	**0.82**	**39.64**	**3.93**

Where, GY= grain yield, NPPP= number of pod per plant, PHT= plant height, SDW = shoot dry weight, NN = number of nodule, BM= Biomass, RDW=root dry weight, CV=coefficient variation

microorganisms, when the pH value of the soil improved due to liming, which might have resulted in increased grain yield. Tigist (2017) reported 172.7 % decrease in grain yield of soybean under unlimed plots by relative to lime treated plots.

Tolerance and susceptibility index of soybean genotypes to acid soils

Considerable variability for soil acidity tolerance and susceptibility among soybean genotypes has been observed in this study. Genotype PI567046A and variety HAWASSA-04 produced the highest tolerance values for grain yield, and hence might be considered the tolerant genotypes (Table 12); while genotype PI423958 was found the most susceptible genotype for grain yield, above ground biomass and number of pods (Table 13). In line with these findings, Kuswantoro (2015) reported significant difference among soybean genotypes in whichMLGG0343 genotype was more tolerant on acidic soil condition than other genotypes, whereas genotype MLGG 0469 showed high sensitivity value for more than seven tested traits. Generally, the results shown in ASAI of shoot dry weight, yield, plant height, above ground biomass, and pods per plant showed that genotype PI567046A and HAWASSA-04 variety gave the highest ASAI value, and low susceptibility value and these genotypes considered as the most tolerant genotypes for most of the tested traits.

Table 12. Tolerance index of soybean genotypes for different soybean traits on acid soil

Genotypes	YLD	PHT	NSPP	NPPP	AGB	SDW	RDW	NN
PI567046A	2.28^a	3.36^a	3.63^a	3.11^a	2.48^a	0.89^g	1.01^f	1.54^{fg}
HAWASSA-04	2.27^a	1.74^b	1.66^c	1.88^c	2.76^a	3.40^a	2.20^c	2.80^c
PI423958	2.20^a	0.60^h	0.41^j	0.60^i	0.66^f	1.88^f	0.93^f	3.75^a
JMALM/PR142-15-SC	2.03^b	1.31^d	1.37^{ef}	1.24^g	1.91^b	2.62^b	2.76^a	2.23^e
JM-HAR/DAV-15-SA	2.03^b	0.96^g	1.53^{cd}	1.52^{de}	1.50^{bcd}	2.69^b	1.27^e	2.19^e
JM-PR142/H3-15-SB	1.82^c	1.55^c	1.54^{cd}	1.48^{de}	2.45^a	1.95^{def}	2.34^{bc}	3.20^b
H-7	1.64^d	0.65^h	1.49^{de}	1.24^g	0.99^{def}	2.02^{cde}	1.24^e	2.33^e
JM-H3/SCS-15-SG	1.58^{de}	1.52^c	1.49^{de}	1.41^{ef}	1.87^b	1.96^{def}	1.61^d	1.51^{fg}
JM-CLK/CRFD-15-SA	1.56^{ed}	1.27^{de}	1.097^h	1.22^g	1.40^{bcde}	0.97^g	2.24^c	1.41^g
BRS268	1.47^e	1.53^c	2.22^b	2.53^b	2.50^a	2.64^b	2.50^b	1.50^{fg}
JM-ALM/H3-15-SC-1	1.35^f	1.24^{def}	1.12^{gh}	1.32^{fg}	1.30^{cde}	0.70^h	1.86^d	0.85^i
SCS-1	1.303^f	1.167^{ef}	0.84^i	0.91^h	0.96^{ef}	0.63^h	1.26^e	1.18^h
JM-CLK/G99-15-SC	1.25^{fg}	1.29^d	1.60^{cd}	1.86^c	1.81^{bc}	2.14^c	0.87^f	1.50^{fg}
JM-CLK/G99-15-SB	1.24^{fg}	1.12^f	1.24^{fg}	1.31^{fg}	0.91^{ef}	1.90^{ef}	0.64^g	1.58^f
JM-DAV/PR142-15-SA	1.17^g	0.85^g	1.22^{gh}	1.56^d	1.045^{def}	2.05^{cd}	1.37^e	2.60^d
Grand Mean	1.68	1.344	1.49	1.55	1.64	1.89	1.56	2.01
LSD	0.118	0.122	0.13	0.13	0.5222	0.133	0.198	0.14
CV	4.197	5.45	5.24	5.029	19.1	4.21	7.4	4.17

Where, NPPP= Number of pod per plant, NSPP= Number of seed per plant, SDW= Shoot dry weight, PHT= Plant height, RDW= Root dry weight, weight, NN= number of nodule per plant, YLD= Yield, AGB = above ground biomass.

Table 13. Susceptibility index of soybean genotypes for different traits on acid soil

GENOTYPES	YLD	PH	NSPP	NPPP	AGB	SDW	RDW	NN
PI567046A	0.193^{cde}	0.027^f	0.130^c	0.150^c	0.203^{ab}	0.296^a	0.190^a	0.320^b
HAWASSA-04	0.100^h	0.047^{de}	0.090^e	0.110^{de}	0.110^{cd}	0.187^g	0.087^e	0.223^{fg}
PI423958	0.297a	0.083^a	0.203^a	0.213^a	0.250^a	0.260^b	0.180^a	0.273^c
JMALM/PR142-15-SC	0.157^{efg}	0.040^{de}	0.0033^i	0.037^f	0.033^{ef}	0.150^h	0.11^{cde}	0.207^{gh}
JM-HAR/DAV-15-SA	0.253^b	0.080^a	0.170^b	0.177^b	0.240^a	0.210^{ef}	0.140^{bc}	0.203^h
JM-PR142/H3-15-SB	0.150^{fg}	0.047^{de}	0.120^c	0.130^d	0.160^{bc}	0.23^{cd}	0.145^b	0.273^c
H-7	0.183^{def}	0.060^{bc}	0.120^{cd}	0.130^d	0.160^{bc}	0.240^c	0.11^{cde}	0.160^i
JM-H3/SCS-15-SG	0.093^h	0.060^{bc}	0.043^h	0.093^e	0.09^{cde}	0.193^{fg}	0.140^{bc}	0.190^h
JM-CLK/CRFD-15-SA	0.220^{bcd}	0.043^{de}	0.097^{de}	0.120^d	0.130^c	0.220^{de}	0.13^{bcd}	0.253^d
BRS268	0.000^j	0.037^{ef}	0.093^e	0.093^e	0.140^{bc}	0.093^i	0.107^{de}	0.060^j
JM-ALM/H3-15-SC-1	0.19ed	0.050^{cd}	0.077^{ef}	0.117^d	0.140^{bc}	0.240^c	0.150^b	0.247^{de}
SCS-1	0.23bc	0.063^b	0.087^{ef}	0.097^e	0.130^c	0.290^a	0.193^a	0.353^a
JM-CLK/G99-15-SC	0.110^h	0.045^{de}	0.067^{fg}	0.130^d	0.09^{cde}	0.160^h	0.13^{bcd}	0.253^d
JM-CLK/G99-15-SB	0.130^{gh}	0.040d^e	0.050^{gh}	0.043^f	0.05^{def}	0.183^g	0.087^e	0.263^{cd}
JM-DAV/PR142-15-SA	0.053^i	0.050^{cd}	0.0033^i	0.017^g	0.033^f	0.157^h	0.020^f	0.233^{ef}
Grand Mean	0.157	0.052	0.09	0.11	0.129	0.207	0.127	0.234
LSD	0.0386	0.013	0.0229	0.0168	0.070	0.0175	0.0295	0.0187
CV	14.69	15.12	15.18	9.11	32.65	5.058	13.91	4.78

Where, NPPP= Number of pod per plant, NSPP= Number of seed per plant, SDW= Shoot dry weight, PHT= Plant height, RDW= Root dry weight, weight, NN= number of nodule per plant, YLD= Yield, AGB = above ground biomass

Correlation Analysis

Grain yield was significantly (P≤ 0.01) and positively correlated with all root and nodule parameters (Table 14). The significant and positive correlation of grain yield with the rooting parameters under acid soil condition indicates the importance of the root parameters for acid soil tolerance. This also implies that selection for acid soil tolerance should consider these important root parameters. Abush *et al.* (2017) reported that significant and positive associations of soybean grain yield with its root characters viz., root volume, root dry and fresh weight. Grain yield is the product of its yield components was highly significant and positively correlated with its grain yield (Table 14). Most authors, such as Ortiz *et al.* (2002) and Abeledo *et al.* (2003) reported that the significant associations of barley grain yield with its yield components. Results obtained in this study on soil treated with lime and phosphorus fertilizer clearly showed that the remarkable increase in number of pods and greatly contributed to increase in grain yield of soybean. Growth parameters, such as shoot dry weight and plant height were positively and significantly (P<0.01) associated with grain yield of soybean (Table 16).

Table 14. Correlations of growth, root, nodulation traits with some of yield and yield related traits at both soil amended condition

	YLD	PHT	NPPP	AGB	NDW	SDW	RV	RDW	NN
YLD	1								
PHT	0.63**	1							
NPPP	0.70**	0.75**	1						
AGB	0.82**	0.74**	0.83**	1					
NDW	0.64**	0.12^{ns}	0.28**	0.40**	1				
SDW	0.76**	0.30**	0.51**	0.60**	0.83**	1			
RV	0.59**	0.47**	0.38**	0.61**	0.34**	0.47**	1		
RDW	0.61**	0.44**	0.42**	0.64**	0.30**	0.51**	0.82**	1	
NN	0.64**	0.17*	0.32**	0.41**	0.82**	0.76**	0.52**	0.48**	1

Where, NPPP: Number of pod per plant, SDW: Shoot dry weight, PHT: Plant height, RDW: Root dry weight, RV: Root volume, NDW: Nodule dry weight, NN: number of nodule, YLD: Yield, AGB: Above ground biomass *: Correlation is significant at the 0.05 level, and **: Correlation is significant at the 0.01 level.

CONCLUSION

Soil acidity has become a great threat in food production through limiting the production potential of the crops because of low availability of nutrients and excess hydrogen and aluminium in exchangeable forms. The major well known acceptable practice to reduce soil acidity is the application of agricultural limestone and fertilizer specifically phosphorus. However, these methods have limited practicality for resource poor farmers to apply high rates of lime as well as mineral fertilizers. Thus, the use of soybean genotypes that are tolerant to acidic soils and produce reasonable good yield under low P fertilization condition is paramount importance. Therefore, this study was conducted to identify soybean genotypes that tolerates low pH and soybean genotypes that respond to optimum lime and P management and to evaluate the combined effect of liming and phosphorus on growth, yield and yield components of soybean genotypes. The treatments were laid down in split plot design with three replications. The four types of soil amendments were applied as main plots, where as fifteen soybean genotypes were assigned to sub-plot treatments.

Considerable variability for soil acidity tolerance among the genotypes has been observed in this study. The existence of significant genotype x amendment interactions for all roots, nodule and yield and yield components parameters imply the presence of differential response of genotypes for different soil amendments. Genotype PI567046A & HAWASSA- 04 variety gave the best performance for most of the traits tested and these are promised genotypes among the other tested. The fact that significant correlations with grain yield were recorded for rooting and nodulation indicates that these traits were important contributors to yield and yield related traits. The main effect of lime and phosphorus, and also their interaction effects significantly influenced plant height, biomass and yield, root dry weight, number of nodule, nodule dry weigh, shoot dry weight, and number of pods per plant. The combination of lime with P application significantly gave the highest number of pod (48 /plant), number of seed (96.2 /plant), above ground biomass (7.05t/ha) and shoot dry weight (9.95g/plant), of soybean from PI567046A genotype.

The overall mean of soybean yields were increased by more than 68.1% over the control due to lime and phosphorus application. From this study, it can be concluded that genotype BRS268, PI567046A and HAWASSA-04 variety supplied with lime and phosphorus or without lime and phosphorus had resulted in higher production and recommended for further evaluation. However, as this study was done for one seasons at one location, the experiment has to be repeated over locations and years to determine the residual effect of phosphorus and lime on the crop and on the soil to draw sound recommendation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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