RESPONSE OF SOYBEAN (*Glycine max* L.) GENOTYPES TO APPLICATION OF LIME AND PHOSPHORUS ON ACIDIC NITISOLS OF METTU, SOUTH WESTERN ETHIOPIA

MSc. THESIS

BY

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JIMMA, ETHIOPIA

RESPONSE OF SOYBEAN (*Glycine max* L.) GENOTYPES TO APPLICATION OF LIME AND PHOSPHORUS ON ACIDIC NITISOL OF METTU, SOUTH WESTERN ETHIOPIA

MSc. Thesis

Submitted to Jimma University College of Agriculture and Veterinary Medicine Department of Natural Resources Management, Postgraduate Program, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Soil Science

BY

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I have incorporated the suggestions and modifications given during the internal thesis defense and got the approval of my advisers. Hence, I hereby kindly request the Department to allow me to submit my thesis for external defense.

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DEDICATION

I dedicated this thesis to my father **Ameyu Bedassa** and my mother **Gelane Zeleke** who have sown the interest of learning in my mind and wishing me a great career throughout my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Thesis. Any scholar matter that is included in the Thesis has been given recognition through citation. This Thesis is submitted in partial fulfillment of the requirement for an MSc Degree at the Jimma University. The Thesis is deposited in the Jimma University Library and is made available to borrowers under the rule of the Library. I solemnly declare that this Thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma or certificate. Brief quotation from this Thesis may be made without special permission provided that accurate and complete acknowledgement of the source is made. Request for permission for extended quotation from or reproduction of this Thesis in whole or in part may be granted by the head of the school or department when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

The author, Tolessa Ameyu, was born in September 1989 at Danno District, West Shewa Zone of the Oromia Regional State. He attended his elementary education at Kerra Garjeda Elementary School from 1997- 2004 and his Secondary School at Seyo High School from 2005-2006. The author attended his preparatory school at Gedo Senior Secondary and preparatory school from 2007-2008. After successful completion of Ethiopian Higher Education Entrance Qualification Certificate Examination (EHEEQCE) in 2008, he joined Ambo University in 2009 and graduated in 2011 with a Bachelor of Science in Plant Science. He was employed since March 2013 by Ethiopian institute of Agricultural Research (EIAR), Jimma Agricultural Research Center, at Mettu sub-center and served as a researcher on integrated soil fertility management and crop productivity improvement. Then in September 2016, he joined the postgraduate program of Jimma University to persue his MSc degree in Soil Science.

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LIST OF ABBREVIATIONS AND ACRONOYMS

AGRA	Alliance for Green Revolution in Africa
ANOVA	Analysis of Variance
ASAI	Acid Soil Adaptability Index
CDI WUR	Center for Development Innovation, Wageningen University and Research
CSA	Central Stastical Agency
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agricultural organization
HARC	Holeta Agricultural Research Center
JARC	Jimma Agricultural Research Center
LR	Lime Requirements
MAP	Mono-ammonium Phosphate
MoARD	Ministry of Agriculture and Rural Development
OM	Organic Matter
SNNP	South Nations Nationalities and People of Ethiopia
SSA	Sub-Saharan Africa

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ABSTRACT

Soybean (Glycine max L.) *is one of the most important oil crops and it is the world's leading source of oil and protein among food legumes. Acidic soils limit the productive potential of crops because of low availability of basic cations and excess of hydrogen and aluminium in exchangeable forms. In Ilu abba bora Zone, soil acidity is a well-known problem limiting crop productivity. This study was conducted to assess the response of soybean genotypes to lime and phosphorus for some of the important growth, root and nodulation characteristics and yield and yield components and to identify soybean genotypes that tolerate low pH soil. Treatments were laid out in a split-plot design, whereby four soil amendments were assigned to main plots i.e. control, lime alone (3457.8 kg ha^{-1}), phosphorus alone (20 kg ha^{-1}) and both lime and phosphorus (3457.8 +20 kg ha^{-1}) and fifteen genotypes were assigned to the sub-plots. Data on growth, root and nodulation characters, yield and yield components, and soil parameters were collected and analyzed using SAS version 9.3 software. 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, except for hundred seed weight where only the main effects of genotypes and amendments were significant. The maximum grain yield of (2120 and 2047.2 kg ha^{-1}) was obtained under Phosphorus alone and combine 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 and mean productivity value indicated that genotype 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. Yield was highly significantly and positively correlated with above ground dry biomass (r=0.82), shoot fresh weight (r=0.81) and shoot dry weight (r=0.76). The soil results revealed that soil pH increased from 4.40 to 4.90 pH while exchangeable acidity decreased from2.72 to1.52 cmol (+)/kg under lime alone, which resulted in improved soil chemical properties. 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. HAWASSA-04 variety and PI567046A genotype 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*

1. INTRODUCTION

Soil acidification is a complex set of processes resulting in the formation of acid soils. The summation of different anthropogenic and natural processes including leaching of exchangeable bases, basic cation uptake by plants, decomposition of organic materials, application of commercial fertilizers and other farming practices produce acidic soils (Brady and Weil, 2002). The major soil forming factors that includes; climate, vegetation and parent material, are among the major factors that increase soil acidity in the country (Mesfin, 2007). Soil acidity is one of the most serious challenges to agricultural production worldwide, in general, and developing countries in particular. Area affected by acidity is estimated at 4 billion ha, representing about 30% of the total ice-free land area of the world (Sumner and Noble, 2003). It is mostly distributed in developing countries, where population growth is fast and demand for food is increasing. 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 Mesfin, (2007), about 40.9 % of the Ethiopian total land is affected by soil acidity, and of these soil 27.7 % are dominated by moderate to weak acid soils (pH in KCl of 4.5 -5.5), and around 13.2 % are strong acid soils (pH in KCl of <4.5). However the recent study showed that about 43% of the Ethiopian arable land is affected by soil acidity (Ethiosis, 2014). In Ethiopia, vast areas of land in the Western, Southern, South-western, and North-western and even the central highlands of the country, which receive high rainfall, are thought to be affected by soil acidity (Mesfin, 2007) attributed to various factors including continuous cropping (in many areas mono-cropping) without the use of the required amount of inputs, increasing use of ammonium based inorganic fertilizer, and concentration of CO_2 in the atmospheric; the problem of soil acidity in the country is apparently increasing both in area coverage and severity of the problem. Theoretically, soil acidity is quantified on the basis of $H^+$and Al^{3+} concentrations of soils. For crop production, soil acidity 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). However, Al^{3+} toxicity is one of the major limiting factors for crop production on acid soils by inhibiting root cell division and elongation, thereby, reducing water and nutrient uptake (Wang *et al*., 2006), poor nodulation or mycorrhizal infections (Delhaize *et al*., 2007), consequently leading to poor plant growth and yield of crops.

Increased soil acidity causes solubilization of Al^{3+}, which is the primary source of toxicity to plants at pH below 5.5, and deficiencies of P, Ca, Mg, N, K and micronutrients (Kariuki *et al*., 2007; Mesfin, 2007). Among these constraints, 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. Also, soil acidity is one of the major problems of soil degradation issues (chemical constraints) that limit the agricultural productivity of Western, South western, mid and highlands of Ethiopian soils. Soil acidity is often an insidious soil degradation process, developing slowly, although indicators, such as falling yields, leaf discolorations in susceptible plants, lack of response to fertilizers may show that soil pH is falling to critical levels. Ilu Abba Bora is one of such areas with very strongly acidic soil. If it is not corrected, acidification can continue until irreparable damage takes in the soil. Therefore, the adjustment and maintenance of soil acidity is very important management of acidic soils to increase crop production using different mechanisms (approaches). Acid infertile soils may be corrected through liming or the use of fertilizers (Verde *et al*., 2013).

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. So, lime and fertilizer management practices are primary importance for proper management of soil acidity. 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; Nyoki and Ndakidemi, 2014). Therefore, there is a need to develop practicable or the best alternative soil acidity mitigating strategy. Low pH tolerance often coexists with tolerance to Al toxicity and low P (Liang *et al*., 2013). For these reasons, development of soybean varieties adapted to acid soil is a promising alternative or supplement to liming and related agronomic practices. Soybean is one of the most important oil grain legume crops, and it is the world's leading source of oil and protein, and is only second next to groundnut in terms of oil content (20%)

among food legumes (Gurmu *et al*., 2009). According to Agricultural Sample Survey of the Central Statics Agency (CSA) (2016/17) there are 130,022.00 private peasant holdings that cultivate about 36,635.79 hectares of land and produced 812,34.659 t $ha^{-1}$of soybean. The average productivity of soybean in the country is, therefore, 2217 kg/ha, while, that of Mettu area is 1.3 t ha^{-1} by far below the national average (CSA, 2016/17); while the potential productivity of soybean in the research plots may reach upto 3.5 t/ha (Abush *et al*., 2017). It could be grown in different agro ecological zones including high altitude up to 2200 meter above sea level altitude and annual RF as low as 500-700 mm, but performs best between 1300 and 1800 m altitude with annual RF of 900-1300 mm, an average annual temperature between 20-25°C and soil pH of 5.5 to 7 (Gurmu, 2009).

Soybean improves soil fertility by capturing nitrogen (N) from the atmosphere. An estimated 300 kg of N ha^{-1} has been reported (Mulongoy, 1992; Hungria *et al*., 2006) and a range of 31-110 kg ha^{-1} reported in another study (Osunde and Bala 2005). Soybean requires 378 kg $ha^{-1}$of N to complete its growth cycle; however, it has the potential to obtain 70 to 80% of its requirement from N fixation (Mulongoy, 1992 and Hungria *et al*., 2006). The critical level for phosphorus (P) and the maintenance range for soybeans is 15ppm. Hence, soil test P levels should be maintained between 15 to 30 ppm. It requires large amounts of N, P, and K as well as a smaller amount of S and some micronutrients (Mulongoy, 1992 and Hungria *et al*., 2006). N nutrition is not a serious problem; as the plant has the inherent ability to obtain most of its N requirement from the atmosphere through N fixation by forming a symbiotic relationship with Rhizobium bacteria in the soil (Mulongoy, 1992 and Hungria *et al*., 2006).

The constraints of soybean production include: lack of application of the right type and amount of fertilizers; soil acidification, deficiency of major plant nutrients, specifically-phosphorus, poor soil fertility management, and poor crop management practices, such as improper weed management, and inappropriate planting time. In addition, the lack of improved varieties having desirable traits such as nutrient use efficiency, disease resistance, and high yielding ability magnified the problem. However, acid soils are one of the most limitations to agricultural production in the study area, and worldwide, including Ethiopia, and Ezeh *et al*. (2007) reported that high concentrations of Al in tropical soils often inhibit crop performance on acid soils. The major consequences of soil acidity includes: reduced yields, poor plant vigor, poor nodulation of legumes, stunted root growth, increased incidence of diseases and abnormal leaf colors. Such problematic soils require careful soil fertility management practices to enhance soybean production and productivity. These include the application of lime, phosphorus and developing variety with desirable root attributes to overcome the acidity related problems. Abush *et al*. (2017) conducted experiments to screen soybean genotypes under low P by considering only P as main factor but in this study lime is also considered as a main factor and the genotypes are different from the previous work.

Therefore, to meet the demand of soybean in Ethiopia including the study area, emphasis should be given to increase the productivity of the crops through the use of genotypes that can tolerate acid stressed soil conditions. Ezeh *et al*. (2007) noted that combining sound management practices with genetic tolerance to low pH could ameliorate negative impacts of acid soil stress on crop performance. Tolerance levels have, however, been reported to be influenced by crop genetic background (Bona, 1994). Foy *et al*. (1993) reported the existence of wide genetic variability among and within the species in crops for tolerance to soil acidity. According to Rao (2001), the genetic improvement of crops for Al toxicity tolerance is a less costly complementary approach, for low-fertility agricultural systems. Thus, selection of genotypes with high adaptability to acid soils is one of the best approaches to increase product ivity of soybean. Therefore, the objectives of this study were:

General objective:

- To identify soybean genotypes that can adapt to acidic soil or respond to acid soil management options for increased soybean productivity on acidic Nitisol of Mettu condition.

Specific objectives:

- To evaluate the combined effect of liming and phosphorus on growth, root and nodulation parameters, yield and yield components of different soybean genotype on acidic Nitisol soil of Mettu condition.
- To identify soybean genotypes that tolerates low pH and low P soil, and soybean genotypes that respond to optimum lime and P management.

2. LITERATURE REVIEW

2.1. Over View of Soybean Production and Productivity in Ethiopia

Soybean (*Glycine max* L.) is one of the very important leguminous and oil crops, cultivated globally and believed first domesticated in China, between 2500-2300 B.C. The crop has had its habitation within South and South East Asia following migration routes among local populations within that region until late 18th century when it was introduced in Europe, being grown as an ornamental crop in England and France (Hartman *et al*., 2011). Soybean quickly gained more relevance in the early 19th century, when it was grown as an animal feed in Yugoslavia. From Europe, the crop spread to other parts of the world through, mostly, British and French imperialism, missionary work and trade (Hartman *et al*., 2011). Soybean were first grown in Ethiopia in the 1950's as a trial and the trial was discontinued because of the yields were very low, and then the trials began again in the late 1960s and with the introduction of new high-yielding cultivars in the 1970s, new interest was generated (Amare, 1987).

Throughout the 1970s, Ethiopia produced 6,000 tons of soybeans in a year, making it one of the top four African soybean producing countries. The current national production of soybean in the country is estimated at 36,635.79 ha (CSA, 2017). Both the production and the area of production for soybean are expected to increase due to growing demand of domestic processing industries and feed (both livestock and poultry) industries. Ethiopia has suitable agro- ecological conditions and vast land for investment in soybean farming or production. There are many favorable locations, particularly in West, South west and East parts of the country including Jimma, Bedele, Chawaka, Assossa, Pawe, Harar, Shashemene, and Arsi (Wijnands *et al*., 2011) while, the actual yield productivity of the crop has been 2217 kg/ha (CSA, 2016/17). However, it is possible to achieve the potential yield of 3500kg/ha (Abush *et al*, .2017). Soybean is important, for production in rotation, especially with cereals, such as maize and sorghum, and counters effects the depletion of plant nutrients in the soil due to continuous monocropping of cereals (CDI-WUR, 2011).

2.2. Importance of Soybean

2.2.1. Nutritional importance of soybean

Currently, the main global importance of soybean (*Glycine max* L.) 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. However, only two percent of the production is used for human consumption worldwide, with the rest being used as animal feed (Hartman *et al*., 2011). 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 derivatives have extensive uses; such as, soy flour adds proteins, and improves the crust color and shelf life of baked goods. Soy isolates lack carbohydrates or fiber, and so is used in many diary-like products, such as cheese, milk, coffee whiteners and meat products (Hartman *et al*., 2011). It has been used as the first line nutritional component in humanitarian aid efforts dealing with hunger stricken masses in various calamities, such as drought, floods, and earthquake because of its high nutritional content per unit weight. Generally, soybean is cultivated for it's the most nutritionally rich value, as its dry seed contains the highest protein and oil content among grain legumes (40 to 42% protein) with a good balance of the essential amino acids and has 18-20% oil on a dry seed weight basis. It is cheap and rich source of protein for poor farmers, who have less access to animal source protein, because of their low purchasing capacity (CDI-WUR, 2011).

2.2.2. Economic importance of soybean

Soybean import to the sub Saharan Africa (SSA) region is estimated at nearly 112,000 MT valued at a little less than US$ 34 million (FAO, 2010). South Africa, Nigeria, and Kenya accounts for nearly 43%, 21%, and 18%, respectively, of the total import volume in the region. Ethiopia, Zambia, Zimbabwe, Botswana, Tanzania, and Gabon also import significant amounts of soybean each year. Soybean export in sub Saharan Africa (SSA) is relatively small, well below 29,000 MT that is estimated worth less than US$ 11 million each year (FAO, 2010).

In Ethiopia the last ten years trend in the volume of exported soybean grain has been increasing. In the year 2008 the highest volume of export has been registered and has immediately declined in 2009 in a significant amount (Mekonnen and Kaleb, 2014). The average volume of annual soybean export is 1.4 million kg (Mekonnen and Kaleb, 2014). This export volume is very far from the volume of imported soybean products. The trade deficit which is the difference between imported and exported volume of soybean is about 138 million kg. On average, it is estimated that the world annual demand of about 300 million tons exceeds the current supply by over 40 million tons (FAO, 2010). Additionally the market value of soybean of US$ 650 ton^{-1} is about two times higher than the value of a ton of common cereals (FAO, 2010). This implies that large market exists, both regionally and internationally, for whole grain soybean and a range of processed products from Africa. The net profits for soybean under the best performing intervention for the favorable AGRA project data of two different sites ranged between US$ 363 $ha^{-1}$and US$ 961 ha^{-1}. Similar ranges of profits for soybeans have been observed for different sites in SSA under the N2Africa project (Woomer *et al*., 2014).

2.2.3. Agronomic Importance of Soybean

As a leguminous crop, soybean is important for crop rotation and intercropping in areas where cereal sole cropping is a common practice. In Southwestern Ethiopia, where maize is the major staple food crop, and grown in mono crop condition, the importance of soybean for crop rotation is paramount. This is mainly because of the fact that mono crop system causes depleted soil fertility, and unbalanced diet to the maize feeders over time. Soybean is unique for its ability to fix nitrogen from atmosphere by symbiotic relationship with Rhizobium bacteria (Coskan and Dogan, 2011). When this mutualistic symbiosis established, rhizobia use plant resources for their own reproduction whereas fixed atmospheric nitrogen is used to meet nitrogen requirement of both itself and the host plants, and other crops that are unable to take their own nitrogen from the air so they need the nitrogen in the soil that the legumes provide for them in a crop rotation. Ghosh *et al.* (2007) reported that nitrogen fixing of soybean in cereal cropping systems increases soil fertility and consequently the productivity of subsequent crops.

Intercropping legumes add value the associated cereal crop like maize by transferring part of fixed N to the maize because of the low N requirements of the legumes (Lupwayi and Kennedy, 2007). Soybeans also give good canopy cover to control soil loss through erosion especially on sloppy lands and control weeds (Khola *et al.,* 1999). Continuous cropping of soybean is not recommended because of it reduce its productivity, it can be grown alternatively with cotton, maize and sorghum, but to avoid build up of crop pests longer rotations are recommended (one in four year avoid build-up of crop pest/disease). Sanginga *et al.* (1995) estimated that by adopting soybean-maize cropping systems, household could boost their incomes by between 50 and 70% relative to continuous cereal cropping.

2.3. Soil Acidity and Its Causes

Soil acidity is a serious agricultural and environmental problem that limits the growth of pasture and crops in many parts of the world including Latin America, North America, Asia, Africa, Europe and Australia (Baligar *et al*., 1993). Yang *et al*. (2012) stated that approximately 43% of the world's tropical land area is classified as acidic, comprising of about 68% of tropical America, 38% of tropical Asia, and 27% of tropical Africa. Acidic soils cover a total of 1.66 billion hectares (ha) in 48 developing countries, while the total area affected by soil acidity is about 4 billion ha (Von Uexkull and Mutert, 1995).

Soil reaction is one of the most important chemical characteristics of the soil solution. Soil reaction is expressed in terms of pH indicating, whether the soil is acidic, alkaline or neutral. Soil pH measures the molar activity (concentration) of hydrogen ions in the soil solution. It is a negative logarithmic scale, so a decrease of one unit in pH value implies an increase in the hydrogen ion concentration by tenfold (Moody and Cong, 2008). Soil pH helps to identify the kinds of chemical reactions that are likely taking place in the soil. It affects nutrient availability and toxicity, microbial activity, and root growth (Moody and Cong, 2008). Solubility of many essential elements for plants and nutrient uptake rates are pH dependant.

Phosphorus is taken up mostly as the primary orthophosphate ion ($H_2PO_4^-$), but some is also absorbed as secondary orthophosphate (HPO_4^{2-}), this latter form increasing as the soil pH increases. It is deficient in most acid soils, mainly due to soluble inorganic P is fixed by Al and Fe and this reaction contributes to less availability of P for crops. The availability of P is influenced by soil pH, exchangeable and soluble Al and Fe (Kochian *et al*., 2004). It is available to a crop at soil pH 6 and 7, and its deficiency increases as the pH declines below 6 in most soils. Many soils are inherently poor in available phosphorus content (Barber, 1995) although the total amount of P in the soil might still be high (Vance *et al*., 2003). Moreover, a large fraction of total soil P is in organic form in many soils and these forms are not directly available to plants (Vance *et al*., 2003). It is commonly bound to iron and aluminium oxides and hydroxides through chemical precipitation or physical adsorption (Kochian *et al*., 2004). As a result of adsorption, and conversion to organic forms, only 10-30% of the applied phosphate mineral fertilizer can be recovered by the crop. This suggests that chemical fertilizer application alone is not a cost effective way of increasing crop production in many P-limiting soils.

Therefore, the use of genotypes/cultivars with improved root traits able to unlock and absorb P from bound P resources and/or effectively utilizing the absorbed P is of paramount importance for enhancing the efficiency of P fertilization. For agricultural purposes, soils with pH values within the range of 5.8 to 7.5 are more trouble free than those with higher or lower pH values (Bohn *et al*., 2001). But, for most of agronomic crops, a soil pH of 6.0 to 7.0 is ideal for crop growth, however, the pH tolerance range for various crop species obviously vary to a significant extent. For example, legumes, as a group, and barley respond better to a pH range between 6.5 and 7.0, whereas oats can tolerate a pH value of 5.5 (Johnston, 2004).

The cause of soil acidity is high amount of precipitation that exceeds evapo-transpiration that leaches appreciable amounts of exchangeable bases from the soil surface. As a result, most of the soils have a pH range of 4.5 to 5.5, and contain low organic matter (< 20 g kg^{-1}) and low nutrient availability (Temesgen *et al*., 2017). Crop management practices, removal of organic matter and continuous application of acid forming fertilizers and the bases in exchangeable form on soils, where leaching is limited, microbial production of nitric and sulfuric acids are among some of the factors that contribute to soil acidity, and leaching of cations in soils is most responsible for increased soil acidity (Mesfin, 2007).

In Ethiopia, soil acidity increase involves climatic factors, such as rainfall, temperature, and topographic factors (Mesfin, 2007). Even plant growth will contribute to acidification; in which a major nutrient uptake process is to exchange hydrogen ions at the root surface for needed base ions, such as calcium, magnesium, and potassium (Marschner, 2011). In the effects of human activity, when acidifying fertilizers particularly, ammonium sulfate and mono-ammonium phosphate (MAP) are added to the soil, nitrification occurs and causes soil acidity. Protons produced by nitrification or any other means, displace exchangeable cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) from clays and other charged colloids, and the nitrate can be leached as the accompanying counter-ion (Roosevelt, 2004). Consumption of nitrate by plants, however, is an alkaline process (because OH^- ions are released during uptake); whereas leaching or runoff loss of nitrate acidifies the soil (because H^+ ions produced during nitrification are left un-neutralized) (Marschner, 2011).

2.4. Distribution of Acid Soils in Ethiopia

Acid soils (soils with pH < 5.5 in the surface layer) constitute 3,950 million ha or 30% of the world's total ice-free land (Uexkull and Muter, 1995). De la Fuente-Martinez and Herrera-Estrella (1999) stated that approximately 43% of the world's tropical land area is classified as acidic, comprising about 68% of tropical America, 38% of tropical Asia, and 27% of tropical Africa. In Africa, 22% or 659 million ha of the total 3.01 billion ha land are acid soils (Uexkull and Muter, 1995). Acidic soils cover a total of 1.66 billion hectares (ha) in 48 developing countries, while the total area affected by soil acidity is about 4 billion ha (Von Uexkull and Mutert, 1995). The total area of Ethiopia is 111.8 million hectare out of these only 79 million of hectare is suitable for agriculture, which strong to weak acid soil accounts 40.9%. Out of these 27.7% considered moderate to weak acid soils with pH 5.8-6.7, while 13.2% is characterized as strong to moderate acidic soils with pH less than 5.5, and these acid soils covers 95% of the cropped area and contain almost 85% of the Ethiopian population (Abdenna. *et al.*,2007, Mesfin, 2007).

Soil acidity is a severe problem in high rainfall areas of Ethiopia, and can lead to decline or complete failure of crop production (Abdenna *et al*., 2007). The most strongly acidic soils are found in Western, South western parts of Ethiopia, the central highlands and the high rainfall areas of North western part of the country. The extent of acidity is believed to increase year to year, due to anthropogenic activity and no in-depth studies were made on the causes and extent of acidity. As a result, its exact extent is difficult to ascertain, but available information indicates that, the Western and Southern parts of Ethiopia are dominantly covered by soils with pH < 5.5 (Mesfin, 2007).

In moving from central (West Shewa) to western Ethiopia (West Wollega) and South Western Ethiopia including Iluabbabora, the degree of soil acidification that is measured in terms of acid saturation percentage is increased (ASP>60). The acidity problem in East and West Wollega zone of Oromia region is critical, and the large proportions exchangeable acidity in these areas was due to exchangeable Al^{3+}, while at West Shewa zone it was due to exchangeable H^+ (Abdenna *et al*., 2007). In these areas, the annual rainfall exceeds the potential evaporation. Similarly, the soils in areas, such as Nedjo, Diga, Ghimbi and Bedi in Oromia; Chencha and Sodo in SNNP; and Gozamin and Senan Woreda in Eastern Gojjam and Awi Zone in West Amahara region have acidic problems in the soil (MoARD, 2006). As a case in point, a site specific study of soils around Assossa and Wollega revealed that in aggregate, some 67 percent had pH values less than 6 and were very strongly to strongly acidic (Mesfin, 2007). Nevertheless, moderately acidic soils (pH 5.5- 6.5) are distributed through much of the rest of the country (Taye, 2008).

2.5. Soil Acidity and Its Effect on Crop Production

Acidity refers to concentration of hydrogen cations in a soil solution (FAO, 2006). The natural pH of a soil depends on the nature of the material from which it was developed (TSO, 2010). Increased soil acidity causes solubilization of Al, which is the primary source of toxicity to plants at pH below 5.5, and deficiencies of P, Ca, Mg, Mo, N, K and micronutrients (Kariuki *et al*., 2007; Mesfin, 2007). Theoretically, soil acidity is quantified on the basis of hydrogen (H^+) and aluminium (Al^{3+}) concentrations of soils. For crop production, however, soil acidity is a complex of numerous factors involving nutrient/element deficiencies and toxicities, low activities of beneficial microorganisms, and reduced plant root growth which limits absorption of nutrients and water (Fageria and Baligar, 2008). However, Al^{3+} toxicity is one of the major limiting factors for crop production on acid soils by inhibiting root cell division and elongation, reducing water and nutrient uptake (Wang *et al*., 2006), poor nodulation or mycorrhizal infections (Kochian *et al*., 2004; Delhaize *et al*., 2007), consequently leading to poor plant growth and yield of crops. Soil acidity can decrease crop yield, seedling emergence and survival, establishment, legume nodulation and root growth (Marschner, 2011).

The detrimental effects of soil acidity normally occurs when the soil pH falls below 4.5 and are mainly, due to toxicities of Al, Mn and to some extent of H^+ ions (Foy *et al.*, 1993). On most acid soils, there are several limiting factors for plant growth, including toxic levels of aluminum, manganese, and iron, as well as deficiencies of some essential elements, such as phosphorus, nitrogen, potassium, calcium, magnesium, and some micronutrients (Kochian *et al*., 2004). Among these constraints, Al toxicity and P deficiency are the most important once, due to their ubiquitous existence and overwhelming impact on plant growth (Kochian *et al*., 2004).The survival and function of beneficial organisms, such as rhizobia and micorrhizae may also be inhibited by soil acidity (Foy *et al*., 1993). Moreover, soil acidity encourages certain nematode infections, such as cereal cyst nematode, and a range of fungal diseases, including club-roots in brassica (*Plasmodiophora brassicae*), fusarium-wilt (Blight) in tomato (*Fusarium oxporum*), and damping-off in legumes (*Pythium*). The incidence of these pathogens can be decreased by lime application (Roosevelt, 2004).

On the other hand, P is easily fixed by clay minerals that are rich in acids soils, including various iron oxides and kaolinite, and hence rendering it unavailable for root uptake. Thus, Al toxicity and P deficiency are considered to be the two main constraints for crop production on acid soils (Barber, 1995). Low-P availability is another important limiting factor to plant growth in acid soils. In most humid tropical and subtropical regions, where acid soils prevail, warm and moist conditions result in weathered soil types (mostly Ustisols, Oxisol), in which free Fe and Al oxides bind native and applied P into forms unavailable to plants (Barber, 1995). Largely, high levels of soil acidity (low soil pH) can affect the biological, chemical and physical properties of the soil, which in turn affect the sustainability of crop production in both managed and natural ecosystems.

In general, influences on soil and plant growth are: a detrimental chemical condition of the soil reducing crop growth and yields. Greater quantities of Al, Fe, and Mn are toxic to almost all cultivated plants. Plants have evolved a number of adaptive mechanisms for growth on low-P soils, and these include the exudation of several solutes by the roots, including organic acids, phosphates, and other compounds that may solubilize P from bound P pools in the soil (especially Fe-P, Al-P compounds, and organic phosphate esters), and thus contribute to P efficiency in plants. In fact, release of organic acids in response to P deficiency has been reported in rape (*Brassica napus*), white lupin (*Lupinus albus*), and purple lupin (*Lupinus pilosus*) (Ligaba *et al*., 2004).

2.6. Management Option of Soil Acidity

Soil acidity is an ongoing natural process which can be augmented via anthropogenic activities. However, with appropriate management practices, soil acidity and its deleterious effects can be mitigated or prevented. Studies have showed the availability of a wide array of possibilities to mitigate the effects of soil acidity. In order to have a successful crop production, acid soil stresses need to be controlled/alleviated. The management options to correct the problem of soil acidity includes: improving nutrient use efficiency, and increase crop production on acidic soils using liming, application of organic materials, appropriate crop rotations and use of plant species and varieties tolerant to Al and Mn toxicity (Sanchez and Salinas, 1981)

2.6.1. Liming and liming materials

Liming is an ancient agricultural practice for rehabilitating acid soils. Limes are materials containing carbonates, oxides or hydroxides that are important to amend soil acidity to raise soil pH and neutralize toxic elements in the soil. Soil pH is used to determine whether or not to lime is necessary and the amount of lime required. Number of liming materials includes: crushed limestone ($CaCO_3$), dolomatic lime ($CaCO_3.MgCO_3$), slaked lime (Ca $(OH)_2$, and quick lime (CaO); which can be used to amend soil acidity. They can be used either separately or in combined forms. Studies have shown that apart from reducing the acidity of the soil by counteracting the effects of excess $H^{+}$and Al^{3+} ions, liming also has several other benefits including, its ability to reduce the toxicity effects of some micro elements by lowering their concentrations; increasing the availability of plant nutrients, such as Ca, P, Mo, and Mg in the soil, and reducing the solubility and leaching of heavy metals (Fageria and Baligar, 2008).

According to Mesfin *et al*. (2014), lime and P applied to acid soils increased pH, Ca, Mg and available P, which in turn improves crop performance. Crops absorb most of these nutrient elements, particularly, Ca, P, and Mg in substantial amounts, and therefore, increasing their amounts in the soil can significantly improved crop yields. Application of lime is, however, affected by factors, such as quality of the liming material, soil texture, soil fertility, crop species and the use of organic manure (Fageria and Baligar, 2008).

Nekesa *et al.* (2005) in Western Kenya found positive response of soybean grain yield to lime application, either alone or combined with P fertilizer**.** The experiment conducted in Nigeria where 2.0 t ha^{-1} and 1 t ha^{-1} lime was applied, and 72% and 48% yield increases was found over no lime treatment respectively (Buri *et al*., 2005). The same authors studied the combined lime-phosphorus effect on Oxisol and Ustisols with pH ranging from 4.1-4.5 and 4.7-5.4, respectively, and reported considerable in maize grain yield from application of both lime and phosphorus. The reason was the increase in pH and availability of other essential nutrient elements. Application of lime significantly increased root and shoot yields of soybean in Nigeria (Anetor and Akinrinde, 2006), grain yields of soybean in Brazil (Caires *et al*., 2006). Similarly, Andric *et al*. (2012) reported increased soybean yields by 44% as a result of lime application.

2.6.2. Use of acid tolerant crops

The several effect of acid soil to crop production can be reduced by growing acid tolerant crops in areas with limited inputs, such as lime (Clark, 1977). Quite a variety of crops have been found to thrive well on acid soils, because of their varying degrees of tolerance to acidity. Chillies, Sweet and Irish potatoes are among the crops that have shown tolerance to acidity and can somewhat do well on acid soils with pH values well below 5.5. Most of the horticultural crops (onions, spinach, carrots, cabbages and cauliflower), however, do not tolerate acidity and can only grow well in soils with pH values above 6.0. Cassava and rice are, however, some of the successful crops so far used in this regard (Buri *et al*., 2005). Several studies have been pointed out that varietal differences in tolerance of Al have been identified in few cereal such as rice, corn and wheat (Kochian *et al.*, 2004), a few legumes such as alfalfa, soybean and pigeon pea (Liao *et al*., 2006)

Many studies have been conducted on plant Al tolerance, and P deficiency on acid soils, and Al toxicity and P deficiency are almost always studied separately as independent factors. In reality, however, Al toxicity and P deficiency often coexist on acid soils, and these two factors may strongly interact through chemical and biochemical reactions. In this regard, inconsistent results have often been reported from different studies on the relationship between plant Al tolerance or P efficiency studied in the laboratory, and the performance of the same genotypes on acid soils. For instance, the relative ranking of Al tolerance in soybean can change when different growth media are used (Villagarcia *et al*., 2001). In another study, soybean genotype 416937 was found to be Al tolerant when studied in hydroponic-based experiments, but was considerably less tolerant when grown on acid soils in the field (Ferrufino *et al*., 200).

In contrast, a soybean genotype that was scored as Al sensitive in hydroponic experiments was found to be relatively tolerant when grown on acid soils (Foy *et al*., 1993). These discrepancies might be due, in part, to overlooking possible interactions between Al and other factors in the soil, particularly P status.

2.7. Response of Crops to Lime and Phosphorus Applications

2.7.1. Response of crops to phosphorus applications

Phosphorus is the second most vital plant nutrient, however it assumes primary significance for legumes, which plays important role in root proliferation, and thereby, atmospheric nitrogen fixation. Phosphorus is crucial in the production of protein, phospholipids and phytin in legume grains (Rahman *et al*., 2008). Singh *et al*. (2008) reported that the yield and nutritional quality of legumes is greatly influenced by application of phosphorus. Its application also plays a vital role in increasing legume yield through its effect on the plant itself and also on the nitrogen fixation process by bacteria. For example, it is widely reported that phosphorus stress may led to reduced growth, and yield in field crops, including legumes, such as soybean. Phosphorus stress reduces nitrogen fixation due to decreased nodule formation and reduced nodule sizes, and finally affecting the yield, and grain quality and quantity (Sadeghipour and Abbasi, 2012).

Effects of P in enhancing N fixation have been demonstrated by various studies. For instance, Mugendi *et al*. (2010) in central highlands of Kenya obtained increased nodule fresh weight with increased levels of P fertilizer up to 25 kg P_2O_5 ha^{-1}. In Nigeria, application of P fertilizer at the rates of 30 kg P_2O_5 ha^{-1} and 60 kg P_2O_5 ha^{-1} significantly increased number of nodules (Ogoke *et al*., 2004). Chiezey and Odunze, (2009) found that Phosphorus application significantly influenced N fixation in Nigeria. In South Africa, Mabapa *et al*. (2010) reported an increase in above ground biomass and grain yields of soybean following the application of 60 kg P_2O_5 ha^{-1}. Phiri *et al*. (2016) reported application of 25 kg P ha^{-1} and 35 kg P ha^{-1} increased the soybean biomass yields by 54% and 70%, respectively, over the control. Increased soybean grain yield and yield components have also been reported after the application of P fertilizers in Nigeria (Kamara *et al.,* 2007). Similarly, Aziz *et al*. (2016) reported that phosphorus applications of 22.5 and 45.0 kg P_2O_5 ha^{-1} increased grain yield by 33.9, and 35.4 %, respectively, and also increased N_2 fixation by 49.39 and 69.82%, respectively, over the unfertilized control in Ghana. In Ethiopia, Workneh and Asfaw (2013) reported that fertilization of 20, 40 and 60 kg P_2O5 ha^{-1} had 16.67, 42.50 and 51.20% yield advantage over the control, respectively.

2.7.2. Response of crops to limes applications

Limes are materials containing carbonates, oxides or hydroxide required to apply on acidic soil to raise soil pH, and in addition, neutralizes toxic elements in the soil. Soil pH is used to determine whether or not to lime a soil (TSO, 2010). Liming materials include $CaCO_3$, Ca $(OH)_2$, CaO and others, which vary according to their neutralizing value and degree of fineness (TSO, 2010). When lime is applied to the soil, Ca^{2+} and Mg^{2+} ions displace H^+, Fe^{2+}, Al^{3+}, Mn^{4+} and Cu^{2+} ions from soil adsorption sites resulting in increase in the soil pH, and other than increasing soil pH, lime also supplies significant amounts of Ca and Mg, depending on the type of liming materials. Indirect effects of lime include increased availability of P, Mo and B, and more favorable conditions for microbially mediated reactions, such as nitrogen fixation and nitrification, and in some cases improved soil structure (Nekesa *et al*., 2005).

It was reported that liming significantly increased nodule number, nodule volume and nodule dry weight per plant as compared to the un-limed treatment in legume crops (Abubakari, 2016). In Croatia, Andric *et al*. (2012) reported increased soybean yield by 44% as a result of lime application over the control treatments. For instance, application of lime significantly increased root and shoot yields of soybean in Nigeria (Anetor and Akinrinde, 2006), yields of soybean in Brazil (Kassel *et al*., 2000; Caires *et al*., 2006). Verde *et al*. (2013) reported yield response of soybean to lime with P-fertilizer over the application of lime or P fertilizer alone in Kenya. Moreover, Workneh *et al*. (2013) reported that the application of lime and phosphorus fertilizer at the same time produced the highest nodule number, nodule volume and nodule dry weight per plants of all the combinations. These authors also reported, the highest number of pods per plant (39.40) was produced when the crop was grown under both limed soil and the application of phosphorus fertilizer. Zerihun and Tolera, (2014) reported that increased faba bean yield ranging from 11% to 23%, as the function of increasing lime application rates up to 6 t ha^{-1}. Mesfin *et al*. (2014) and Hirpa *et al*. (2013) also found considerable differences among common bean genotypes, as a result of lime application.

2.8. Acid Soil Tolerance of Crops and Mechanisms of Tolerance

Tolerance to acid soil is the ability of crops to grow better, produce dry matter, develop fewer deficiency symptoms when grown at low or toxic levels of the mineral element, and give better yield (Graham *et al.,* 2002). Tolerance and susceptibility index is important mechanisms because it brings about differences in the performance of a test material in acid soil condition and also determines whether a genotype is adapted or not adapted to acid soil. Plant species and varieties vary widely in tolerance to acidic soils (excess Al) in the growth medium. Since tolerance and sensitivity is genetically determined, selection is possible for better Al tolerance in soybean. Foy (1993) stated that some acid-tolerant plant such as barley, rice and corn can increase the pH of the nutrient solution in which they are grown.

Kuswantoro (2015) reported different increasing pH levels in the rhizosphere in various seedling ages of six soybean genotypes. Previous studies have also reported high genetic variability in soybean for performance under low P conditions for various economically important attributes (Wang *et al*., 2008). Kuswantoro (2015) reported significant difference among soybean genotypes in which MLGG 0343 genotype more tolerant on acidic soil condition than other genotypes, whereas genotype MLGG 0469 showed high sensitivity for more than seven traits tested. Sensitivity to acid soils limits the usage of soybean in some cropping systems. Sensitive genotypes tend to accumulate higher amount of aluminium (Al) in their root tissues. Therefore, information on genotypes is important for the development and recommendation of varieties that are suitable for growth in acid soil conditions.

Mechanisms of acid tolerance are classified as those that prevent Al ions from entering the root apical cells through Apo-plastic mechanisms or that detoxify internal Al that is Symplastic mechanisms (Kochian *et al*., 2004). In symplastic mechanisms, Al enters the cytoplasm and is detoxified once inside the cell by complexation with organic compounds (Kochian *et al.*, 2004). Several compounds can form stable complexes with Al inside the cell, including organic acids, such as citrate, oxalate, malate and proteins (Ma and Miyasaka, 1998). Free Al^{3+} or Al complexes with chelating agents can be transported to cell vacuoles, where they are stored without causing toxicity (Kochian *et al*., 2004).

The following Al exclusion mechanisms have been reported: release of phenolic compounds, mucilage formation and pH barrier resulting from increased pH in the rhizosphere (Kuswantoro, 2015) and organic acid exudation (Magalhaes *et al*., 2007). Roots of several plant species secrete organic acids in response to Al, which are mediated by membrane transporters, resulting in the formation of non-toxic complexes with the metal. Thus, this mechanism prevents Al from crossing the plasma membrane into the symplast. Although organic acid exudation is a conserved Al tolerance mechanism being present in different plant species.

The Al-activated mechanism of malate exudation is well described in wheat (Sasaki *et al*., 2004), rye (Ligaba *et al*., 2006), whereas the mechanism of Al tolerance in maize, soybean, sorghum, and barley involves mainly citrate release (Maron *et al*., 2010). In maize, root citrate and oxalate exudation are likely involved in Al tolerance. However, Pineros *et al*. (2005) reported low correlation between citrate exudation and Al tolerance in maize, suggesting that this species has other complementary mechanisms enabling them to tolerate Al. In addition to malate, citrate exudation has also been reported to contribute to Al tolerance in wheat and rye (Yokosho *et al*., 2011). In rice, citrate exudation (Yokosho *et al*., 2011) as well as symplastic mechanisms are likely to contribute to the extreme Al tolerance in this species.

2.9. Effects of Lime and Phosphorus on Chemical Properties of Acid Soils

2.9.1. Soil reactions (pH) and its managements

Soil reaction is one of the most important chemical characteristics of the soil solution. Soil reaction is expressed in terms of pH indicating whether the soil is acidic, alkaline or neutral. Soil pH measures the molar activity (concentration) of hydrogen ions in the soil solution. It is a negative logarithmic scale, and hence, a decrease of one unit in pH value implies an increase in the hydrogen ion concentration by tenfold (Moody and Cong, 2008). Soil pH helps to identify the kinds of chemical reactions that are likely taking place in the soil. It affects nutrient availability and toxicity, microbial activity, and root growth. For agricultural purposes, soils with pH values within the range of 5.8 to 7.5 are more trouble free than those with higher or lower values (Bohn *et al*., 2001). On acid soils, pH is a critical parameter that influences the physiology of the roots (Hissinger *et al*., 2003), where it is expressed in root alteration including root weight, volume and length.

Correcting soil pH to a suitable value requires the removal of excess hydrogen (H^+) ions produced by various processes in the soil, by applying liming materials, such as agricultural lime (calcium carbonate), dolomite (magnesium carbonate plus calcium carbonate), or other materials containing basic cations capable to replace excess H^+ (Moody and Cong, 2008). Liming raises soil pH, base saturation, and Ca and Mg contents, and reduces aluminum concentration on acid soils (Fageria and Baligar, 2008). In addition, liming can also cause the aluminum (Al) and manganese (Mn) to move from the soil solution back into solid (non-toxic) chemical forms. Buni, (2015) reported that, soil pH increased significantly from 5.03 in the plots without lime to 6.72 at the lime rate of 3750 kg $CaCO_3$ ha^{-1}. Temesgen *et al.* (2017), reported that soil pH was increased and Al^{3+} was markedly reduced to a negligible level after two years of liming at Holeta Agricultural Research Center (HARC). According to these authors, liming at the rate of 0.55, 1.1, 1.65 and 2.2 t ha^{-1} increased soil pH by 0.48, 0.71, 0.85 and 1.1 units, and decreased Al^{3+} by 0.88, 1.11, 1.20 and 1.19 mill equivalents per 100 g of soil, respectively.

Murata *et al*. (2002) also reported that application of lime at the rate of 2 t ha^{-1} significantly increased topsoil pH values from 4.6 to 6.0. Mesfin *et al*. (2014) also reported that lime combined with P fertilizer gave the highest mean value of soil pH (6.3); while phosphorus fertilizer applied alone had the least pH (5.2).

2.9.2. Available phosphorus

Total phosphorus (P) gives an indication of the total reserve of the nutrient in the soil and it is a poor indicator of the availability level, since most of the soil P might be fixed (Anetor and Akinrinde, 2006). Phosphorus deficiency problems are compounded by widespread high phosphorus fixation capacity of acid soils, since elemental P is very reactive chemically; and hence, it is not present in the pure state rather than found only in chemical combinations with other elements (Gupta, 2000). Fageria and Baligar (2008) reported that a linear increase in extractable P with increasing soil pH in the range of 5.3-6.9of surface soil in Brazilian Oxisol.

Edmeades and Perrott (2004) reported that liming increased the availability of P by adsorption and stimulating the mineralization of organic P on acid soils of New Zealand. Fageria and Baligar, (2008) also reported that the application of lime increased the extractable P in the pH range of 5.0-6.5, after, and thereafter, it was decreased in the Brazilian Oxisol, which might be associated with the release of P ions from Al and Fe oxides, which were responsible for P fixation (Fageria and Baligar, 2008).

Bohn *et al*. (2001) reported that soils that are high in exchangeable and soluble Al, liming might increase plant P uptake by decreasing Al, rather than increasing P availability. This might be due to improved root growth where Al toxicity is alleviated, allowing a greater volume of soil to be explored. Temasgen *et al.* (2017) also reported that liming at the rate of 2.2 t ha^{-1} improved P availability by 77.6 % as compared to no liming.

Sven *et al.* (2015) reported an increase in P availability with comparable amounts of added lime in field trials. Sarker *et al*. (2014) observed the highest available phosphorus in the soil with the application of lime at the rate of 2 t ha^{-1}, which might indicate that the application of lime contributed to the release of some amounts of fixed P, and made available for the crop. But, deficiency of P cannot be replaced by lime application alone. As a result, on acidic soils that are deficient in available P, OC, and TN, the application of P together with lime is important increasing a crop production (Mesfin *et al*., 2014). Another short-term management strategy in reducing Al^{3+} ion toxicity to seedlings is band application of fertilizer P. Band application of P fertilizer on wheat crop has dramatically reduced Al toxicity and increased wheat yield (Havlin *et al*., 1999).

2.9.3. Exchangeable acidity

Exchangeable acidity consisted of exchangeable aluminum and H^{+} that might be present in the exchange sites (Bohn *et al*., 2001). Exchangeable acidity in soils is almost entirely due to Al^{3+} ions (Bohn *et al*., 2001). This is because only Al^{3+} is a common exchangeable cation in moderately to strongly acidic soils (Bohn *et al*., 2001). Exchangeable Al normally occurs in significant amounts, only at soil pH values less than 5.5. Furthermore, as the pH is lowered, the concentration of soluble aluminum, which is toxic, increases (Bohn *et al*., 2001). The poor growth of plants on acid soils has been associated with the concentration of Al in the soil solution. The Al^{3+}cation can be toxic to roots which is one of the major reasons that soil acidity can affect plant growth. In addition to direct toxic effects of soluble Al^{3+} to plants, it replaces the plant nutrient cations such as Ca and Mg, and simultaneously acts as strong adsorber of phosphate (Marschner, 2011).

Liming soils to reduce toxic levels of A1 is recognized necessary for optimal crop production on acid soils. Liming resulted in the increase of exchangeable Ca, and thus, in percentage base saturation, with concomitant decreases in levels of exchangeable Al, Fe and Mn (Fageria and Baligar, 2008). When lime is added to acidic soils, the activity of Al^{3+} is reduced by precipitation as $Al(OH)_3$. Liming rises soil pH, while greatly reducing extractable Al and increasing crop yields (Havlin *et al*., 1999). Applications of lime highly decreased exchangeable acidity and Al^{+3}, as the level of applied lime rates increased. For instant exchangeable acidity decreased from the initial level of 1.32 to 0.1 cmol/kg when lime was applied at the rate of 2.2 t ha^{-1} (Temasgen *et al.,* 2017).

2.9.4. Exchangeable bases (Ca, Mg, K, and Na)

The removal of base cations, especially Ca and Mg, by leaching and erosion results in their replacement by acidic cations like H, Al and Fe on exchange sites and in the soil solution (Johnston, 2004). The development of soil acidity results in the lowering of negative charge with a concomitant loss of exchangeable Ca and Mg, and also in bringing in to the solution of Al that may or may not become associated with the surface charge. Tigist (2017) reported that the, application of lime increased the soil exchangeable K by 59 %, irrespective of the levels above the control treatments. Adeleye *et al*. (2010) reported increased soil exchangeable K when manure was applied combined with lime.

2.9.5. Cation exchange capacity (CEC)

The cation exchange capacity (CEC) of a soil represents the total quantity of negative charge available to attract cations in the soil solution. It is one of the most important chemical properties of the soil as it strongly influences nutrient availability (Havlin *et al*., 1999). High CEC values are usually associated with humus compared to those exhibited by the inorganic clays, especially kaolinite and Fe, Al oxides (Brady and Weil, 2002). Buni (2015) reported the highest (33.34) and the lowest (19.18 cmol (+) kg^{-1}) values of CEC under lime treated and untreated plots, respectively.

2.9.6. Soil organic carbon and total nitrogen

Soil organic carbon (OC) is critical for maintaining the chemical, physical and biological health of the soil. On soils that contain predominantly "variable" charged clay minerals, (such as most acidic upland soils); soil OC is a key determinant of CEC, which increases as the former increases. As soil OC is highly correlated with total N, the amount of N mineralization (i.e. conversion of organic N compounds to ammonium-N) increases as the SOC increases (Moody and Cong, 2008). On acidic soils, the turnover of OM and recycling of the nutrients it contains, especially N and P, are slowed, because decrease in microbial activity. For example, the nitrifying bacteria that oxidize ammonium to nitrate are most active between pH 6 and 8

(Roosevelt, 2004). Therefore, plants that to utilize ammonium forms of nitrogen have a considerable advantage on acid soils. Ammonium ions may accumulate on acid forest soils, because the microbes that neutralize organic N to ammonia are less dependent on soil pH than the nitrifying organisms (Bohn *et al*., 2001).

3. MATERIALS AND METHODS

3.1. Description of the Study Site

The study was carried out at Mettu Agricultural Research Sub Center of Jimma Agricultural Research Center, under the Ethiopian Institute of Agricultural Research (EIAR) 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. Geographically, it is located at latitude 8°19' 0" N longitude 35°35' 0"E at an altitude of 1550 m.a.s.l. Agro-climatically, it has been characterized as Tepid (slightly warm) 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).

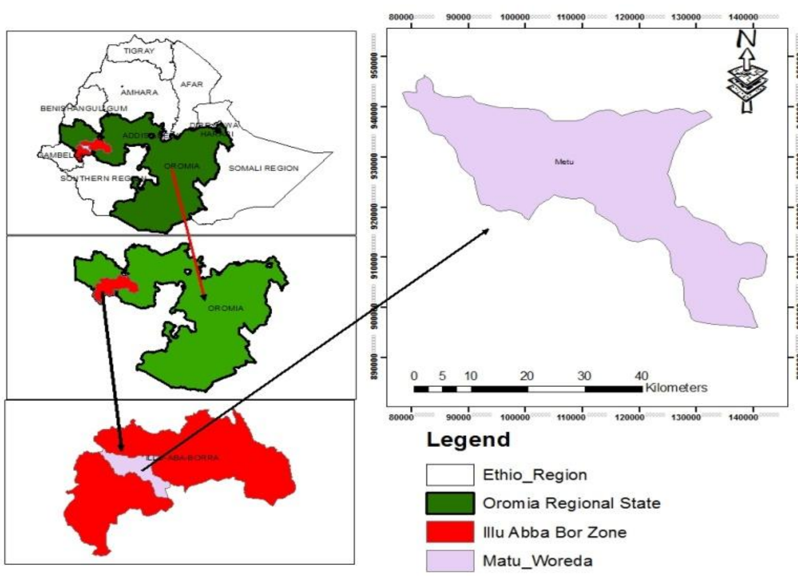

Figure: 1 Location Map of the study area.

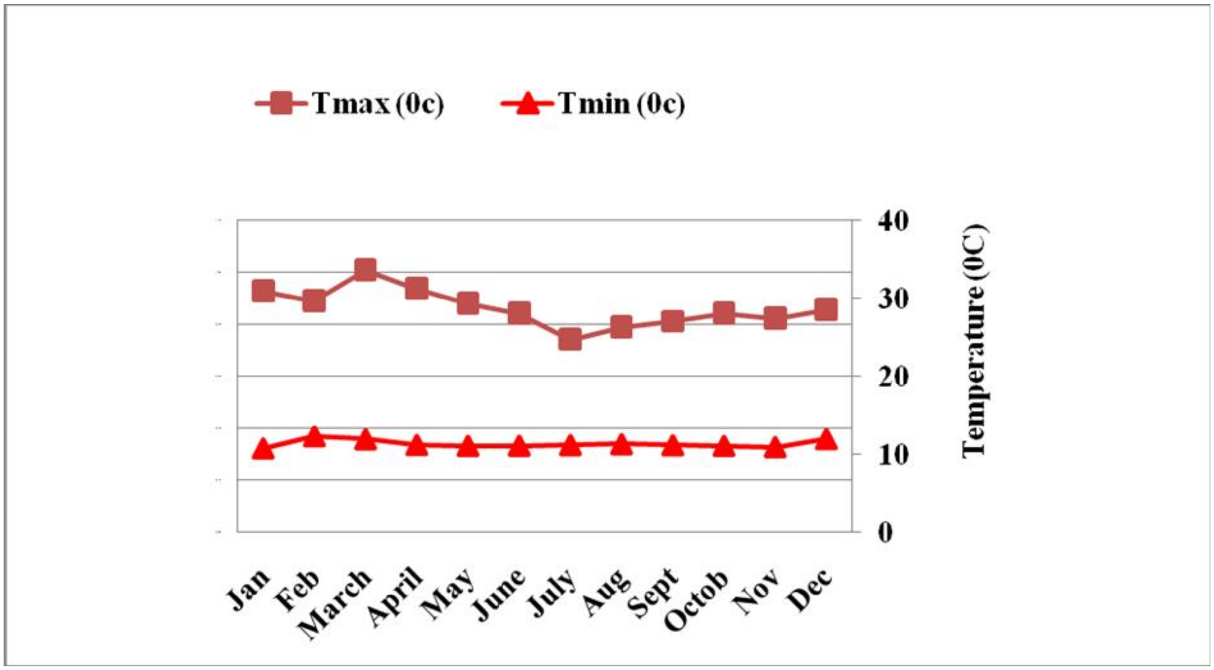

Figure: 2. Mean minimum and maximum temperatures (°C) of Mettu during crop growth period in 2017

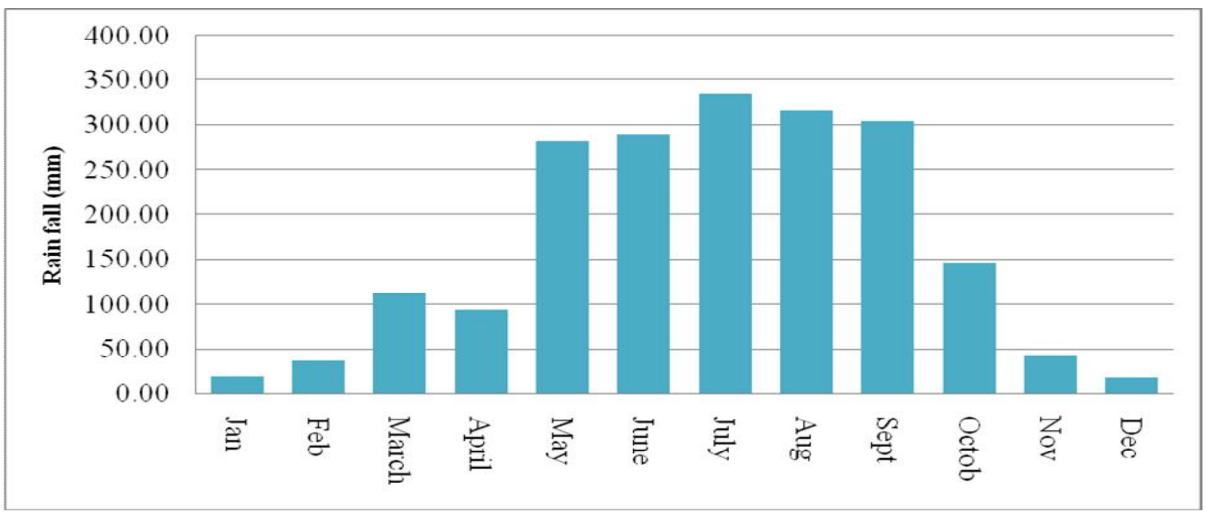

Figure: 3. Monthly total rainfall (mm) of Mettu during crop growth period in 2017

Source: Jimma Agricultural Research, Mettu Sub center Agro meteorology Department

3.2. Soil Sampling, Preparation and Analysis before Planting and After Harvesting

Prior to the field experimentation both undisturbed and disturbed samples were collected. Three 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).

Ten random disturbed composite soil samples (0-15 cm depth) were collected and a composite soil sample was made. 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, percentage base saturation (PBS) was calculated by dividing the sum of the charge equivalents of the base forming cations (Ca, Mg, Na and K) by the CEC of the soil and multiplying by 100 and all others are determined following the standard procedures as described below under after harvesting.

After harvesting, the soil samples were collected main plot-wise from each replication from the surface 0-15 cm depth, and composite samples were made for selected soil chemical analysis, and then the soil samples were air dried, sieved to pass through 2 mm sieve, and placed in a labeled plastic bags and submitted to JARC soil laboratory for soil chemical properties analysis. Organic matter was determined using wet oxidation. Total N was determined by Kjeldahl method, as described by Black (1965).

Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K and Na) were determined after extracting the soil samples by ammonium acetate ($1NH_4OAc$) at pH 7.0. Exchangeable Ca and Mg in the extracts were analyzed using Atomic Absorption Spectrophotometer (AAS), and Na and K were analyzed by flame photometer as described by Chapman (1965) and Rowell (1994). Available soil P was determined using Bray-II method, as described by Bray and Kurtz, (1945). The soil pH was determined in soil water suspension of 1:2.5 (soil: water ratio) using pH meter, as described by Van Reeuwijk (1992). Exchangeable acidity was determined by saturating the soil samples with potassium chloride solution and titrates with sodium hydroxide as described by Mclean (1965). From the same extractant, exchangeable Al in the soil was titrated with a standard solution of 0.02M HCl.

3.3. Determination of Lime Requirements

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.

$$LR, \frac{CcCo3kg}{ha} = \frac{Cmol\frac{EA}{Kg}\, of\ soil * 0.15m * 10m^2 * BD\left(\frac{g}{cm^3}\right) * 1000 \times crop\ factor}{2000} \quad \text{Equation 1}$$

Where: BD = bulk density, EA = exchangeable acidity (exch. H^+ + Al^{3+}), LR= lime requirements, 0.15m= plough depth/depth of lime incorporation. Crop factor = 1.5

2000 = to convert exchangeable acidity per kg of soil to per hectare

Initial pH of the soil = 4.4, EA = 2.72cmol $kg^{-1}$of soil, B.D = 1.13g/ cm^{-3}

$$\mathbf{LR}, CaCO3\frac{kg}{ha} = \frac{cmol\frac{2.72}{kg}\, of soil * 0.15m * 10^2m^2 * 1.13\left(\frac{g}{cm^3}\right) * 1000}{2000} * 1.5 = 3457.8\ kg/ha$$

3.4. 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 (JM-DAV/PR 142-15-SA, JM-PR142/H3-15-SB, JM-CLK/CRFD-15-SA, JM-ALM/PR142-15-SC, JM-ALM/H3-15-SC-1, BRS268, JM-HAR/DAV-15-SA, JM-CLK/G99-15-SC, JM-CLK/G99-15-SB, JM-H3/SCS-15-SG, Pl 567046A, SCS-1, Pl 423958, H-7 and HAWASSA -04). 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, because of high precision is required from sub-plot treatments/genotypes. Both lime and P fertilizers were obtained from JARC. The different soybean genotypes were identified from various variety trials at JARC including previous soil acidity tolerance screening trials.

The lime requirement (LR) of the soil for the plots was determined based on EA or acid saturation of the experimental soil. The lime rate was, therefore, 3457.8 kg/ha based on exchangeable acidity of the soil. Calcium carbonate was used as the source of lime and the whole doses of lime of the respective main plot treatment were broadcasted uniformly by hand and mixed in the top 15 cm soil layer, a month before sowing, to mix lime with soil properly. Phosphorus fertilizer recommended (46 kg P_2O_5 $ha^{-1}$from Triple Super Phosphate) (Shahid *et al.,* 2009) was applied at planting and mixed with the soil. Soybean seeds were planted on June 20, 2017 as per the recommended soybean planting period. 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

Table 1. Soybean Genotypes Used for the Experiment

Genotypes	Back ground information and Source	Year of introduced
JM-DAV/PR 142-15-SA	Inbreed line from local crosses	
JM-PR142/H3-15-SB	Inbreed line from local crosses	
JM-CLK/CRFD-15-SA	Inbreed line from local crosses	
JM-ALM/PR142-15-SC	Inbreed line from local crosses	
JM-ALM/H3-15-SC-1	Inbreed line from local crosses	
BRS 268	Introduced from Brazil	2016
JM-HAR/DAV-15-SA	Inbreed line from local crosses	
JM-CLK/G99-15-SC	Inbreed line from local crosses	
JM-CLK/G99-15-SB	Inbreed line from local crosses	
JM-H3/SCS-15-SG	Inbreed line from local crosses	
Pl 567046A	Introduced from USA	2015
SCS-1	Pipe line from Pawe	
Pl 423958	Introduced from USA	2015
H-7	Pipe line from Mozambique ARI	
HAWASSA- 04	Released variety from Hawassa	

Source: Jimma Agricultural Research Center (JARC)

Table 2. Treatment Combinations and Description

Pedigree of genotypes (Sub-plot treatments)	Soil amendments (Main plot treatments)			
JM-DAV/PR 142-15-SA	L	C	P	LP
JM-PR142/H3-15-SB	L	C	P	LP
JM-CLK/CRFD-15-SA	L	C	P	LP
JM-ALM/PR142-15-SC	L	C	P	LP
JM-ALM/H3-15-SC-1	L	C	P	LP
BRS 268	L	C	P	LP
JM-HAR/DAV-15-SA	L	C	P	LP
JM-CLK/G99-15-SC	L	C	P	LP
JM-CLK/G99-15-SB	L	C	P	LP
JM-H3/SCS-15-SG	L	C	P	LP
Pl 567046A	L	C	P	LP
SCS-1	L	C	P	LP
Pl 423958	L	C	P	LP
H-7	L	C	P	LP
HAWASSA- 04	L	C	P	LP

L= Lime treated alone, C= Control (no amendments) P= phosphorus treated alone, LP= both lime and phosphorus treated

3.5. Data Collection and Measurements

3.5.1. Growth parameters

Plant height: to evaluate the effect of the treatments on soybean development, five plants per plot were randomly selected before harvest and their heights were measured using a tape measure and the mean height of the five plants was recorded as plant height in cm

Shoot fresh weight: this is the weight of shoots of five plants measured on randomly selected five plants from each plot and the mean of shoot fresh weight 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 of shoot dry weight was recorded.

3.5.2. Nodulation and root data

Nodule and root traits were measured by carefully uprooting five randomly selected plants along with the soil from each plot. Then the soil was removed by washing the root and nodules gently in a plastic container taking care not to damage the root and not to lose any nodule

Root volume: the root samples of five plants were collected and immersed carefully in 1000 ml capacity plastic cylinder which is filled up to 700ml with water. The volume of water displaced by root obtained from five plants was recorded and averaged as root volume per plant

Root dry weight: the roots of five plants were dried at 70 ^{O}c for 48 hrs in an oven to a constant weight. The dry roots were then weighted and the average root dry weight was recorded

Root fresh weight: this is the weight of roots of five plants was measured on randomly selected five plants from each plots and averaged as root fresh weight per plant

Total number of nodule: which is the count of all the nodules formed by the roots of five plants were counted at 50% flowering stage and averaged as number of nodules per plant

Total nodule fresh weight: the nodules were collected from five plants, and then weighted and the average of nodule fresh weight was recorded

Total 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

3.5.3. Yield and yield components

Plant stand count: the number of plants from harvestable plot area (net plot area) was counted at establishment and at harvesting

Number of pods per plant: was counted from five randomly selected plants from two middle rows at harvest maturity and expressed as an average of each plant

Hundred seeds weight (g): was counted from the harvested bulk of seeds per net plot randomly and their weight (g) was determined at 10% (Standard moisture content for pulse crops) seed moisture content by using a sensitive balance

Number of seeds per plant: was counted from five randomly selected plants from middle rows at harvest maturity and expressed as an average of each plant

Grain yield (kg/ha): 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 the weight was converted to kg ha^{-1}

Grain yield (at 10% moisture content) kg ha^{-1} = GW * (100-MCA) / (100-MCD)... Equation 2

Where, GW= fresh grain weight, MCA= moisture content of fresh grain, MCD= moisture content of grains at 10% moisture

Above ground dry-biomass (t ha^{-1}): the total above ground 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 and expressed in t ha^{-1}.

Tolerance index: Soil acidity stress tolerance was calculated based on mean grain yield differences between the amended and unamended plots of each genotype (Howeler, 1991) as indicated below:

$$\text{Soil acidity tolerance index(SATI)} = \frac{(\text{GYLTP}) * (\text{GYLUP})}{(\mu\text{GYALUP})^2}$$ ……….. Equation 3

GYLTP= Grain yield of lime treated plots, GYLUP= Grain yield of lime untreated plots (μGYALUP)^2= Mean of grain yield of all lime untreated plots

Reduction percentage: The relative yield reduction percentage due to susceptibility to soil acidity stress of each genotype was calculated based on the formula below (Howeler, 1991):

$\text{RGYR} = 1 - \frac{\text{GYLUTP}}{\text{GYLTP}} * 100$ ….. Equation 4, Where GYLUTP = grain yield of lime untreated plot and GYLTP = grain yield of lime treated plot of each genotype

Susceptibility index (SASI) = (GYLTP - GYLUTP) .

GYLTP * (1 - [μGYLUTP/μGYLTP])…………. Equation 5

Where GYLTP = grain yield of lime treated plot, GYLUTP = grain yield of lime untreated plot and μ = mean.

Mean productivity (MP) = (GYLTP+ GYLUTP) / 2............ Equation 6

3.6. 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 $P \leq 0.05$. Correlation analysis was carried between the parameters to determine magnitude and degree of their relation.

The statistical model for split plot design experiment is given by:

$Yijk = \mu + ri + mj + mij + sk + (ms)jk + eijk$ ……………. Equation 7

where, $yijk$= the observation of i^{th} replication, j^{th} main plot and k^{th} sub-plot $\mu =$, Overall mean, ri= replication effect, mj= amendment effect or main plot treatment effect, mij= amendment error or main plot error i.e. error (a), sk= subplot treatment effect or genotype effect, $(ms)jk$= amendment*genotype effect or interaction effect, $eijk$= error component for subplot or genotype and interaction or error (b).

4. RESULTS AND DISCUSSION

4.1. Response of Soybean Genotypes to Lime and Phosphorus for Different Traits

There were highly significant differences ($p \leq 0.01$) among genotypes and amendments for all growth, yield and yield components, root and nodulation parameters, that is total nodule fresh and dry weight, total nodule number, root fresh and dry weight and root volume, plant height, shoot dry and fresh weight, total number of pod and seed per plant, above ground biomass and hundred seed weight (Appendix Table1_14, Table 3). The interaction of amendments*genoty pes was also highly significant($p\leq0.01$) for all growth, yield and yield components, root and n odulation parameters, except for hundred seed weight only the main effect of amendments an d genotypes were significant (Appendix Table 1-14, Table 3).

Table 3. Mean squares of amendments, genotypes, and genotype * amendment interaction for different trait at Mettu

	Mean squares					Grand
Parameters	A	Error (a)	G	G*A	Error(b)	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
Shoot fresh weight(gm)	2080.7**	0.38	310.39**	44.75**	0.33	24.83
No of nodule per plant	5523.6**	0.15	675.59**	113.9**	0.88	39.637
Nodule fresh weight(gm)	3.0596**	0.0092	1.2592**	0.1118**	0.01264	1.12118
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 fresh weight(gm)	14.172**	0.0762	4.6805**	0.2975**	0.0625	2.963
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
Number of seed per plant	2437.25**	2.149	1601.85**	145.08**	3.39	47.0544
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
Hundred seed weight(gm)	24.03**	3.86	51.89**	2.88^{ns}	2.83	14.588

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

Similarly, there were highly significant ($p\leq0.01$) differences among genotypes for mean productivity, tolerance and susceptibility index based on all growth, yield and yield components, root and nodulation parameters i.e., total nodule number, dry weight, plant height, shoot dry, number of pod and seed per plant, and above ground biomass (Table 4).

Table 4. Mean squares of genotypes, replication and error for TI, SI, MP and different soybean traits at Mettu in 2017

Parameters	Tolerance index (TI)			Susceptibility index (SI)			Mean Productivity(MP)		
	Rep	G	Error	Rep	G	Error	Rep	G	Error
AGB (tha^{-1})	0.31	1.381**	0.097	0.00374	0.01443**	0.00179	0.5094	2.062**	0.1067
YLD (kg ha^{-1})	0.024	0.472**	0.00498	0.00231	0.0185**	0.00053	7090.34	216391.3**	1995.07
NPPP(Nº)	0.02059	1.144**	0.006	0.000027	0.00798**	0.0001	1.447	72.226**	0.33515
NSPP(Nº)	0.00314	1.546**	0.006178	0.00002	0.009**	0.000187	0.5242	343.66**	1.384
PHT(cm)	0.00566	1.2576**	0.00536	0.00001556	0.000072**	0.000061	1.1369	331.144**	1.1487
SDW(gm)	0.01789	1.9296**	0.006359	0.00012667	0.00916**	0.00011	0.0311	4.62658**	0.01164
NN(Nº)	0.0051	1.9548**	0.007	0.00000889	0.01414**	0.000125	0.0987	192.27**	0.407
RDW(gm)	0.00447	1.316**	0.1402	0.000069	0.006149**	0.00031	0.00008	0.0822**	0.00093

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, MP= mean productivity

4.2. Growth Parameters

4.2.1. Plant height

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, followed by the same genotype with the plant height of 73.27 cm on the control plots(without lime and P) (Table 5). The first tallest genotype: PI567046A gave 221% increasing over the shortest genotype: PI423958 i.e., 26.2cm under the control soil main effect (Table 5). 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 5). This result is in-line with the finding of Mesfin *et al*. (2014) who 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 liming that neutralized soil acidity, which in turn might have improved the availability of plant nutrients, particularly phosphorus and calcium and lowered the concentration of toxic cations, mainly Al^{3+} ions. This in turn, improves plant growth, most likely resulted from the enhanced conditions for seedling growth. The application of P fertilizer together with lime amendment has a very important role, which might increase the availability of applied P, and also helps in raising pH of the soil and reduce the effect of acidity on the performance of the crop. However, phosphorous 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.

The genotypes planted under the control soil conditions reduced in performance compared to amended main plots, in which the highest percentage (36.56%) decrease for plant height was showed on genotype PI423958; while the lowest percentage decrease (4.39%) was found on genotype JMALM/PR142-15-SC (Table 5). This result might show that genotype PI423958 responded well to the soil amendments or sensitive to soil acidity. In line with this finding Tigist, (2017) reported 36.4% plant height decrease in soybean on unlimed acid soil compared with limed acid soil.

Table 5. 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.

4.2.2. Shoot dry and fresh weight per plant

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 was statistically at pars with JM-ALM/H3-15-SC-1 (2.38g) and PI567046A (2.29g) genotypes under the control plots (Table 6). The top genotype showed 405.1% shoot dry weight increase over the genotype that produced the lowest shoot dry weight. 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. Kuswantoro (2015) also reported significant differences among soybean genotypes for shoot growth, in which MLGG 0343 genotype showed the highest shoot dry weight on acidic soil condition and genotype MLGG 0469 showed less shoot dry weight.

The genotypes are responded to the applied lime and phosphorus amendments. The reduction of shoot dry weight under the control or acidic soil condition might be due to Al toxicity, and low Ca, Mg and P concentrations in the shoot, which resulted in decreased photosynthetic capacity that directly affected, shoot growth and development. According to Vance *et al*. (2003), plant dry weight might contain up to 0.5% phosphorus, which is involved in an array of process in plants, such as photosynthesis, respiration, energy generation, and as an integral component of several plant structures, such as phospholipids. Murata *et al*. (2003) also reported that on acid soils, Al content of both the root and leaf of the plant is surged, and the Mg contents of both the root and leaf decreased, correspondingly. The authors also reported decrease in shoot dry weight of soybean with decreasing soil pH, Mg and Ca concentrations. Similar results were reported in soybean, where maximum amounts of shoot dry matter were recorded with integrated use of lime and phosphorus (Amir *et al*., 2013).

HAWASSA-04 variety gave the highest shoot fresh weight of 42.87 and 42.616g per plant on combined application of P with lime and P alone, respectively. The lowest shoot fresh weight (7.59g) was obtained from genotype SCS-1 on the control plot, which gave 464.8% shoot fresh weight decrease over the top genotype (Table 6). The released variety, HAWASSA-04 produced the highest shoot fresh weight at the control main plot, which shows that this variety is among the acid soil tolerant genotypes.

This might be mainly attributed to the inherent and genetic factor involved in the control of shoot dry and fresh weight. Mg, P and Ca deficiency also affected shoot fresh weight, which is supported by the work of Abou *et al*. (2002), who reported that high Mn concentration was involved in shortening the shoot, and affected shoot fresh weight. The stress, due to acidity reduces leaf size of the crops, which affects shoot weight. This confirms the positive interaction between phosphorus and lime applied to the soils, which might be due to soil ameliorated by liming, and supplied with adequate phosphorus nutrients have more vegetative growth, longer linear growth rate, and more dry matter accumulations, which are directly related to an increment in shoot weight. Such increment shoot weight might also be due to decreased exchangeable Al as a result of liming.

The poor performance of plants for shoot dry and fresh weights 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, and also plays an important role in the activation of a number of enzymes important in protein synthesis and P reactions. 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. This shows that genotype BRS268 is more tolerant and PI567046A is more responsive to shoot weight. 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. Meriga *et al*. (2004) also reported that Al toxicity decreased the photosynthetic activity of soybean plants and the preservation of high transpiration induced a reduction in water use efficiency on acid soils.

Anetor and Akinrinde (2006) also reported that application of lime and P increased root and shoot fresh weight of soybean by decreasing Al concentration in the leaf in Nigeria. In wheat, liming increased shoot weight and grain yield of Al- sensitive genotype by 60% and head number by 32% (Tang *et al*., 2001). Fageria and Baligar (2008) also reported that, shoot dry matter of common bean increased with the application of lime, as well as, phosphorus, which indicated that interaction between lime and P in this case was synergistic.

Table 6. The interaction effect of amendments and genotypes on Shoot dry and fresh weight of soybean genotypes under acid soil condition in field at Metu during 2017/18 cropping season

Genotypes	Shoot dry weight(g)				SDW- RP (%)			Shoot fresh weight(g)				SFW-RP (%)		
	L	C	P	LP	L	P	LP	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	30.42^{fg}	24.44^{k}	42.87^{a}	42.62^{a}	19.66	42.99	42.65
JM-HAR/DAV-15-SA	4.83^{pqr}	4.97^{opq}	6.16^{ghijk}	9.22^{b}	-2.90	19.36	46.1	20.02^{on}	19.88^{o}	26.24^{i}	40.49^{b}	0.68	24.24	50.90
PI423958	6.48^{ghi}	3.69^{u}	7.06^{def}	8.64^{c}	43.06	47.69	57.26	24.56^{k}	14.30^{u}	30.07^{fg}	37.25^{d}	41.76	52.44	61.60
H-7	5.18^{pon}	4.02^{tu}	4.54^{qrst}	8.52^{c}	22.28	11.44	52.75	21.19^{mn}	16.12^{rs}	18.54^{pq}	37.14^{d}	23.95	13.04	56.59
JM-PR142/H3-15-SB	5.40^{mno}	3.99^{tu}	7.18^{de}	8.30^{c}	26.11	44.48	51.93	21.51^{m}	15.62st	29.13^{gh}	36.84^{d}	27.37	46.38	57.60
JM-ALM/PR142-15-SC	6.16^{ghijk}	5.45^{mno}	8.14^{c}	8.16^{c}	11.57	33.07	33.24	28.30^{h}	25.69^{ijk}	38.93^{c}	33.54^{e}	9.22	34.01	23.40
JM-H3/SCS-15-SG	5.58^{lmn}	4.38^{rst}	7.32^{d}	7.57^{d}	21.40	40.05	42.11	22.29^{lm}	17.31^{qr}	30.86^{f}	32.40^{e}	22.38	43.92	46.59
JM-CLK/G99-15-SB	7.57^{d}	4.38^{rst}	6.14^{hijkl}	7.35^{d}	42.19	28.63	40.41	28.58^{h}	16.15^{rs}	23.17^{l}	28.54^{h}	43.49	30.30	43.41
JM-CLK/G99-15-SC	5.72^{klmn}	4.81^{pqr}	6.70^{efg}	7.56^{d}	15.91	28.24	36.38	23.12^{l}	17.46^{q}	26.05^{ij}	30.84^{f}	24.44	32.96	43.36
BRS268	5.93^{ijklm}	5.95^{ijklm}	7.39^{d}	7.52^{d}	-0.34	19.49	20.88	25.30^{ijk}	25.21^{ijk}	32.49^{e}	32.67^{e}	0.37	22.43	22.84
PI567046A	6.32^{ghij}	2.29^{w}	5.91^{jklm}	6.62^{fgh}	63.77	61.25	65.42	29.98^{fg}	8.930^{w}	26.15^{ij}	32.34^{e}	70.21	65.85	72.39
JM-ALM/H3-15-SC-1	2.94^{v}	2.38^{w}	4.59^{qrs}	5.02^{opq}	19.05	48.15	52.62	12.44^{v}	9.780^{w}	19.66^{op}	23.03^{l}	21.36	50.25	57.54
JM-CLK/CRFD-15-SA	4.34^{rst}	2.92^{v}	3.63^{u}	5.62^{klmn}	32.72	19.56	48.04	19.11^{op}	12.77^{v}	14.76^{tu}	28.07^{h}	33.17	13.48	54.51
SCS-1	3.60^{u}	1.97^{w}	4.12^{stu}	5.43^{mno}	45.28	52.14	63.72	15.76st	7.590^{x}	17.44^{q}	24.86^{jk}	51.84	56.47	69.47
JM-DAV/PR142-15-SA	4.76^{pqr}	4.78^{pqr}	6.08^{hijkl}	7.29^{d}	-0.40	21.38	34.43	19.78^{op}	19.96^{no}	26.22^{i}	33.05^{e}	-0.89	23.89	39.62
Mean	**5.45^{c}**	**4.123^{d}**	**6.236^{b}**	**7.519^{a}**	23.8	34.4	45.8	**22.83^{c}**	**16.75^{d}**	**26.84^{b}**	**32.92^{a}**	**25.9**	**36.8**	**49.5**
	CV(b) : 2.68		**CV(a)=4.45**					**CV(b): 2.33**	**CV(a)=2.6**					

Where, L= Lime treated alone, P= Phosphorus treated alone, LP= lime and phosphorus treated, SDW= shoot dry weight, SFW= shoot 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

4.3. Root and Nodulation Parameters

4.3.1. Number of nodules per plant

The highest total 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 (Table7) which showed about 406.7% difference with the top genotype. The high performance of genotype PI423958 for almost all of the nodulation characteristics was shown in (Tables7). 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. Correa *et al.* (2001) also reported that, soil acidity significantly decreased nodule numbers by 20-33%, in two different red clover genotypes tested.

The response of genotypes to the applied phosphorus and lime for number of nodule might be due to phosphorus plays a significant role in legume nodulation through its ability to enhance root development and proliferation thereby, providing the bacteria more sites for infection and initiation of nodule formation, and liming might be increases the availability of calcium which enhance root development and root nodulation. Genotype: SCS-1 showed high decrease percentage of 71.9% and genotype BRS268 showed low decrease of -0.1%. This observation agrees with Abush *et al*. (2017) who 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. Ogoke *et al*. (2004) also reported that application of P fertilizer at the rates of 30 and 60 kg P_2O_5 ha^{-1} significantly increased number of nodules.

Abubakari (2016) reported that liming significantly increased nodule number per plant as compared to the un-limed treatment in legume crops. Application of lime with P fertilizer improves soil environmental conditions for the development of rhizobia population and leucaena nodulation (Kisinyo *et al*., 2016). Ahiabor *et al*. (2014) also reported that an increased number of nodules per plant up to the highest rate of phosphorus (45 kg P_2O_5 ha^{-1}) plus liming or Rhizobium inoculation. The adverse effects of soil acidity on nodulation and nitrogen fixation were also reported by Bambara and Ndakidemi (2010).

4.3.2. Nodule dry and fresh weight per plant

Genotype PI423958 gave the highest nodule dry weight per plant of 0.5g or 500mg and 0.48 gm or 480mg under the combined application of P with lime, and P treated alone main effects, respectively. The lowest nodule dry weight per plant (0.07g or 70mg) was recorded from a genotype SCS-1 on the control main plot, which was statistically at pars with JM-ALM/H3-15-SC-1 and JM-CLK/CRFD-15-SA genotypes on the control and lime treated alone main plots, which showed more than 614.28% nodule dry weight difference with the highest genotype (Table7). 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 7). 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).

The performance of genotype JM-HAR/DAV-15-SA was relatively high on the control soil condition compared to its performance on the lime with P combined amendment, which might be shows its tolerant to soil acidity. 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%.

Genotypes responded to phosphorus and liming amendments, which might be due to their positive effect on nodule weight and nodule numbers. Workneh *et al*. (2013) reported that, combined application of lime and P produced the highest nodule number, volume and dry weight of soybean. The authors also reported that Rhizobia bacteria are sensitive to soil acidity, and require P and adequate soil moisture for their multiplication. Suryantini, (2014) reported that, the highest nodule dry weight (350 mg/plant) of soybean from combined amendment of lime and P. Liming increased nodule dry weight per plant as compared to the un-limed soil in legume crops (Abubakari, 2016).

Genotype PR142/H3-15-SB and PI423958 with respective mean nodule fresh weight of 2.31 and 2.12g under the combined amendment of P with lime and P alone respectively; gave the highest nodule fresh weight; while the lowest total nodule fresh weight (0.327 and 0.49g) per plant was obtained on the control and lime treated alone main plot from genotype SCS-1, respectively (Table 8). Genotype which produces more nodules should have greater potential to fix more atmospheric nitrogen. The genotypes responded to the applied lime and P amendment, which might be due to the effect of P on nodule number and size. From the correlation results of this study the nodule fresh weight was highly correlated with number of nodules which indicated that the nodule fresh weight increased as the number of nodules increased. Mugendi *et al*. (2010) in the central highlands of Kenya obtained increased nodule fresh weight with increased levels of P fertilizer up to 25 kg P_2O_5 ha^{-1}. The authors also observed increment in fresh and dry weights of nodules in soybean in the P and lime alone treated plants as compared to the control.

Table 7. 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^{i}	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.

4.3.3. Root volume

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, which was statistically at pars with genotypes PI423958, SCS-1 and JM-CLK/G99-15-SC grown on the control plot, and H-7 on the P treated alone main plot, and the highest genotype showed 300% of root volume per plant increase over the lowest performing genotypes (Table 8). 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. Root hairs substantially increased the root surface area for ion uptake. Some plant species/genotypes are adapted to produce longer and more root hairs under P deficient conditions. Eticha and Schenk (2001) reported that, root hairs contributed up to 63% of the total phosphorus uptake under P deficient condition. According to these authors, 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 8. Interaction effect of different amendments and genotypes on Root volume (ml) and Nodule fresh weight (g) of soybean genotypes under acid soil condition in field at Metu

Genotypes	Root volume (ml)				RV-RP			Nodule fresh weight (g)				NFW-RP		
	L	C	P	LP	L	P	LP	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	1.11^{n-s}	1.05^{n-t}	1.45^{f-i}	2.31^{a}	5.4	27.6	54.5
JM-ALM/PR142-15-SC	3.67^{bac}	2.77^{f-i}	4.00^{a}	4.00^{a}	24.67	30.75	30.75	1.01^{p-u}	0.97^{q-w}	1.57^{e-h}	1.56^{e-i}	4.0	38.2	37.8
PI567046A	2.33^{kij}	1.67^{omn}	3.33^{b-e}	3.73^{ba}	28.12	49.68	55.04	1.16^{m-q}	0.72^{yzx}	1.43^{f-j}	1.45^{f-i}	37.9	49.7	50.3
BRS268	2.33^{i-l}	2.33^{i-l}	3.27^{b-f}	3.67^{bac}	0.00	28.65	36.55	1.05^{n-t}	1.02^{o-t}	1.23^{k-n}	1.23^{j-n}	2.9	17.1	17.1
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	0.64^{Ayz}	0.54^{Az}	0.65^{Ayz}	0.79^{v-y}	15.6	16.9	31.6
HAWASSA-04	2.33^{kij}	2.33^{i-l}	3.67^{bac}	3.53^{a-d}	0.00	36.55	33.97	1.43^{f-j}	1.22^{k-o}	1.75^{de}	1.97^{bc}	14.7	30.3	38.1
PI423958	2.33^{kij}	1.33^{onp}	3.33^{b-e}	3.40^{a-e}	42.86	60.01	60.79	1.61^{fe}	1.15^{n-r}	2.12^{ba}	2.12^{ba}	28.6	45.8	45.8
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	0.83^{t-x}	0.53^{Az}	0.79^{v-y}	0.81^{u-y}	36.1	32.9	34.6
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	1.23^{j-n}	0.99^{p-v}	1.45^{f-i}	1.41^{g-k}	19.5	31.7	29.8
SCS-1	2.77^{f-i}	1.53^{m-p}	3.00^{d-h}	3.06^{c-g}	44.66	48.90	49.90	0.49^{AB}	0.32^{B}	0.72^{yzx}	1.00^{p-u}	34.7	55.6	68.0
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	0.96^{r-w}	0.94^{s-w}	1.36^{i-m}	1.45^{f-i}	2.1	30.9	35.2
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	0.97^{p-v}	1.47^{f-i}	1.70^{e}	1.90^{dc}	-51.5	13.5	22.6
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	1.05^{n-t}	1.04^{n-t}	1.37^{h-l}	1.57^{e-h}	1.0	24.1	33.8
H-7	2.00^{j-m}	1.67^{omn}	1.33^{onp}	2.00^{j-m}	16.15	-25.8	16.15	1.18^{l-p}	1.09^{n-s}	1.01^{p-u}	1.57^{e-h}	7.6	-7.9	30.6
JM-CLK/G99-15-SB	1.67^{omn}	1.33^{onp}	1.00^{p}	1.73^{l-o}	20.51	-33.3	23.08	1.45^{f-i}	0.73^{wyx}	1.27^{k-n}	1.59^{feg}	49.7	42.5	54.1
Mean	**2.34^{c}**	**1.88^{d}**	**2.82^{b}**	**3.13^{a}**	**19.00**	**26.0**	**37.84**	**1.08^{c}**	**0.92^{d}**	**1.32^{b}**	**1.52^{a}**	**13.9**	**29.9**	**38.9**
	CV(a)= 11.2		**CV(b) : 16.92**					**CV(a)= 8.6**		**CV(b): 9.27**				

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.

4.3.4. Root dry and fresh weight

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; while both genotypes produced among the highest (1.25gm/plant) root dry weight under both lime and P treated main plot conditions (Table 9); 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 9). 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 9).

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, including root length and number of lateral roots. Root hair length and density is affected by soil acidity (Haling *et al*., 2011) led to root dry weight alteration. This indicated that JM-PR142/H3-15-SB genotype is more responsive than tolerant based on root dry weight. In line with this result, Liang *et al*. (2013) reported that acid tolerance of two soybean genotypes in which, the P-efficient soybean genotype (HN89) adapted better to acid soil conditions than the P-inefficient genotype (HN112) and shows greater root dry weight, especially under conditions of P supply. Kuswantoro (2015) also reported that among the fifteen soybean genotypes tested MLGG 0064 genotype showed the highest root dry weight under the control soil condition (pH 7), while the lowest root length was shown by genotype MLGG 0377 in Mn toxicity condition, which shows varietal difference for acid soil adaptation.

Genotype SCS-1 showed high decrease of 59.16% and genotypes: H-7 and BRS268 showed low decrease of -6.03 and 0.00% for root dry weight, respectively. In line with this result Abush *et al*. (2017) who reported that the reductions of root parameters i.e. root volume, root dry and fresh weight of soybean genotypes under phosphorus untreated acid soil. Except genetic factor that increased or maintained number of lateral roots, the other factor that increase root growth and development are concentration of Ca (Murata *et al*., 2003) or P concentration (Hissinger *et al*., 2003) which increase root dry weight.

Genotypes: JM-ALM/PR142-15-SC,BRS268 and JM-PR142/H3-15-SB with respective mean root fresh weight of 4.67, 4.33, and 4.44gm under the combined amendment of lime and P, and genotypes: JM-ALM/PR142-15-SC, JM-PR142/H3-15-SB, and BRS268, with respective mean root fresh weight of 4.53, 4.37 and 4.27g under P alone amended soil condition, and genotype JM-ALM/PR142-15-SC with root fresh weight of 4.19gm, under lime alone amended conditions , were among the highest fresh root weight producing genotypes. The lowest root fresh weight per plant (1.54 and 1.60g) was obtained on the control main plots from genotypes: JM-CLK/G99-15-SC and JM-CLK/G99-15-SB respectively, which was statistically at par with SCS-1, PI567046A, PI423958, H-7 and JM-DAV/PR142-15-SA on the control plots (Table 9). The difference among the genotypes might be attributed to genetic factors responsible for tolerance to soil acidity. In line with this result, Belachew and Stoddard (2017) reported root fresh weight of tolerant accessions, including GLA 1103, NC 58 and Kassa were not affected by soil acidity, whereas that of Aurora, Tesfa and Babylon was severely affected.

The performance of genotype JM-ALM/PR142-15-SC was relatively higher on the control soil condition compared to its performance on lime and P amended main plots, the genotype might be phosphate uptake efficient and mineralize organic P by releasing acid phosphatases and phytases, thereby, increasing soil available P to increase root growth, and sustain high yield. In line with this results Abush *et al*. (2017) reported two genotypes viz., PR-142 (26) and AA-42-52, produced the highest fresh root weight than other genotypes tested. Similarly, Rincon *et al*. (2003) evaluated the variation among six soybean genotypes viz., PI416937, H2L16, N95-SH-259, PI07859-2, PI471938, and young for their ability to absorb water, which was assessed based on root hydraulic conductance in flowing hydroponics condition. The authors reported high genotypic variability for root anatomical traits, which affected water movement through the root system under adequate watering conditions. They also stated that such genetic variations inspire studying the root hydraulic conductance and performance of soybean for root growth under different stress condition.

High soil acidity can reduce root growth, nutrient availability and thus would result in poor root weight and crop performance (Ezeh *et al*.,2007). From my results genotype SCS-1 showed high decrease of 55.1% and genotype BRS268 showed low decrease of 0.00%. This alteration of root weight might be influenced by amendments and genetic factors. This alteration might also due to the low pH that inhibits root growth (Liang *et al*., 2013) as well as the Mn toxicity. The result agrees with the report of Uguru *et al*. (2012) that soil pH had strong impact on the soybean root growth, agronomic performance, and yield traits.

Table 9. The interaction effect of amendments and genotypes on Root dry and fresh weight of soybean grown under acid soil in field at Mettu during 2017/18 cropping season

Genotypes	Root dry weight (g)				RDW-RP (%)			Root fresh weight(g)				RFW-RP (%)		
	L	C	P	LP	L	P	LP	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	3.07^{j-q}	2.96^{l-s}	4.367^{abc}	4.33^{a-d}	3.60	32.2	31.6
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	4.187^{a-f}	3.62^{f-j}	4.53^{ba}	4.67^{a}	13.4	20.1	22.5
BRS268	0.84^{o-s}	0.83^{p-s}	1.19^{bc}	1.19^{bc}	1.20	30.3	30.3	3.02^{k-s}	3.02^{k-r}	4.27^{a-e}	4.44^{bac}	0.00	29.3	32.0
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	3.37^{h-o}	2.57^{q-y}	3.34^{i-o}	3.67^{f-i}	23.7	23.1	30.0
JM-ALM/H3-15-SC-1	0.71^{wxy}	0.65^{zyA}	1.08^{ed}	1.10^{d}	8.50	39.8	40.9	2.45^{s-z}	2.57^{q-y}	3.41^{h-n}	3.70^{e-i}	-4.9	24.6	30.5
HAWASSA-04	0.81^{qrst}	0.81^{q-t}	1.06^{ed}	1.06^{def}	0.00	23.6	23.6	2.84^{o-v}	2.83^{p-v}	3.93^{c-h}	4.03^{b-g}	0.40	28.0	29.8
SCS-1	0.80^{rstu}	0.43^{D}	0.96^{h-k}	1.05^{d-g}	46.3	55.2	59.0	3.03^{k-r}	1.66^{BC}	3.18^{i-p}	3.69^{e-i}	45.2	47.8	55.0
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	2.48^{r-z}	2.26^{Av-z}	3.54^{g-l}	3.66^{f-j}	8.90	36.2	38.3
PI567046A	0.75^{t-x}	0.43^{D}	0.90^{k-o}	0.92^{j-m}	42.7	52.2	53.3	2.88^{n-u}	1.95^{ABCz}	3.74^{d-i}	3.67^{f-i}	32.3	47.9	46.9
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	2.26^{Aw-z}	2.19^{ABw-z}	2.87^{n-u}	2.90^{m-t}	3.10	23.7	24.5
PI423958	0.59^{ABC}	0.43^{D}	0.88^{l-p}	0.86^{m-r}	27.1	51.1	50.0	2.37^{At-z}	1.64^{CB}	3.47^{g-m}	3.56^{g-k}	30.8	52.7	53.9
H-7	0.63^{zAB}	0.58^{ABC}	0.54^{C}	0.84^{n-s}	7.90	-7.4	31.0	2.28^{Av-z}	2.02^{AyBCz}	2.04^{xyzABC}	2.91^{m-t}	11.4	1.00	30.6
JM-DAV/PR142-15-SA	0.74^{xwv}	0.72^{xw}	0.68^{xzy}	0.75^{t-w}	2.70	-5.9	4.00	2.05^{ABCw-z}	2.04^{xAyBCz}	2.38^{At-z}	2.90^{m-t}	0.50	14.3	29.7
JM-CLK/G99-15-SC	0.65^{zyA}	0.47^{D}	0.72^{xw}	0.72^{vwx}	27.7	34.7	34.7	2.29^{Av-z}	1.54^{C}	2.58^{q-x}	2.61^{p-w}	32.8	40.3	41.0
JM-CLK/G99-15-SB	0.64^{zA}	0.44^{D}	0.56^{BC}	0.58^{ABC}	31.3	21.4	24.1	2.20^{ABw-z}	1.60^{C}	1.82^{ABC}	2.32^{u-z}	27.3	12.1	31.0
Mean	**0.74^{c}**	**0.63^{d}**	**0.93^{b}**	**0.98^{a}**	**15.7**	**30.9**	**35.7**	**2.72^{c}**	**2.29^{d}**	**3.29^{b}**	**3.55^{a}**	**15.2**	**28.9**	**35.1**
	CV(a)= 4.23		**CV(b): 5.71**					**CV(a)= 9.32**		**CV(b): 8.43**				

L= Lime treated alone, P= Phosphorus treated alone, LP= Lime and Phosphorus treated, CV= Coefficient of variation, RDW= root dry weight, RFW= root fresh 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

4.4. Yield and Yield Components

4.4.1. Total number of pods per plant

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 10), which was about 396.4% of pod number difference with the highest genotype. Genotypes: PI567046A and BRS268 produced the highest number of pods per plant under the control soil condition, and were among the top performing genotypes across different soil amendments for number of pods (Table 10).

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, which is supported by the works of Habtamu (2017) who 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.

Generally, the genotypes responded to the applied lime and P, which might be due to lime and phosphorus enhanced vegetative growth, thereby, enabling the plant to bear higher number of pods than the untreated soil condition, 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). Okpara and Muoneke (2007) reported that the application of lime with P significantly increased number of pods per plant for soybeans. Workneh *et al*. (2013) also reported that combined application of lime and phosphorus produced the highest pods per plant than their separate application.

4.4.2. Total number of seeds per plant

Genotype PI567046A gave the highest number of seeds per plant (96.2) under the combined application of lime with P; while, the lowest number of seeds per plant (14.33) were obtained on genotype PI4239589 under the control main plots, which was about 571.3% seeds per plant decrease over the highest number of seeds producing genotype (Table 10). The response of genotypes across amendments had significant influence on the total number of seeds per plant. Fageria and Santos (2008) reported that the number of seeds per plant in different common bean genotypes varied and attributed the difference due to the genetic variation of cultivars.

The positive response of genotypes to applied lime and P might be due to the improvement of soil pH in response to lime amendment, which enhanced growth and yield of the plant, as a result of increased availability of P that might have increased intensity of photosynthesis, flowering, seed formation and fruiting. Mesfin *et al*. (2014) and Hirpa *et al*. (2013) reported considerable differences in the number of seeds per plant among common bean genotypes in response to lime and P application. Chalk *et al*. (2010) also reported that the beneficial effects of lime with P for legumes grown on acidic soil, in which liming of acid soils significantly increased number of seeds of haricot bean, this may be because of the fact that acidic soil was neutralized by the applied lime.

Table 10. The interaction effect of amendments and genotypes on number of pod and seed per plant under acid soil condition at Metu during 2017/18 main cropping season

Genotypes	Number pod per plant(No)				NP-RP (%)			Number of seed per plant(No)				NS-RP (%)		
	L	C	P	LP	L	P	LP	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	92.33^{b}	55.87^{gh}	77.20^{c}	96.20^{a}	39.5	27.63	41.92
BRS268	30.34^{g}	27.60^{jk}	38.14^{c}	38.00^{c}	9.03	27.6	27.37	47.73^{i-l}	47.73^{ijkl}	69.40^{d}	68.53^{d}	0.00	31.22	30.35
HAWASSA-04	29.27^{h}	22.94^{pq}	26.67^{kl}	34.00^{e}	21.6	13.9	32.53	60.73^{e}	41.53^{q-v}	55.13^{h}	58.87^{efg}	31.6	24.67	29.45
JM-CLK/G99-15-SB	22.94^{pq}	21.80^{rs}	23.14^{po}	25.00^{mn}	4.97	5.79	12.80	38.93^{vw}	39.13^{uvw}	46.00^{j-n}	46.80^{j-m}	-0.51	14.93	16.39
JM-CLK/G99-15-SC	22.54^{pqr}	21.94^{qrs}	26.20^{l}	35.27^{d}	2.66	16.2	37.79	43.13^{n-r}	43.07^{n-r}	48.07^{i-k}	54.87^{h}	0.150	10.40	21.51
JM-CLK/CRFD-15-SA	22.54^{pqr}	18.07^{Az}	19.27^{xy}	28.00^{ij}	19.8	6.23	35.48	40.33^{r-v}	33.47^{Ayz}	35.13^{x-z}	48.40^{ij}	17.02	4.740	30.85
JM-PR142/H3-15-SB	21.54^{rst}	19.47^{wxy}	26.67^{kl}	31.47^{f}	9.63	27.0	38.14	43.67^{n-q}	37.13^{xw}	54.80^{h}	61.33^{e}	14.96	32.24	39.45
H-7	21.34^{stu}	18.00^{Az}	25.90^{lm}	28.53^{hij}	15.6	30.5	36.91	39.67^{s-w}	36.87^{xw}	57.00^{fgh}	59.80^{ef}	7.060	35.32	38.35
JM-ALM/H3-15-SC-1	21.27^{stuv}	18.93^{yz}	26.80^{kl}	29.00^{hi}	10.9	29.3	34.71	39.07^{uwv}	35.27^{xy}	47.73^{i-l}	47.20^{j-m}	9.720	26.11	25.28
JM-H3/SCS-15-SG	20.54^{tuv}	20.47^{uvw}	22.50^{pqr}	28.53^{hij}	0.36	9.04	28.26	44.27^{m-q}	43.53^{n-q}	43.00^{n-r}	50.67^{i}	1.660	-1.24	14.08
JM-ALM/PR142-15-SC	20.27^{vwx}	21.34^{stu}	24.00^{no}	24.14^{no}	-5.2	11.0	11.60	44.90^{l-p}	44.67^{l-p}	46.80^{j-m}	45.27^{k-o}	0.520	4.560	1.330
JM-HAR/DAV-15-SA	19.27^{xy}	17.40^{AB}	24.90^{n}	36.14^{d}	9.69	30.1	51.85	34.33^{Axyz}	31.87^{AB}	45.27^{k-o}	70.93^{d}	7.180	29.60	55.07
JM-DAV/PR142-15-SA	24.33^{n}	24.80^{n}	26.07^{l}	26.20^{l}	-1.9	4.87	5.340	42.77^{o-s}	42.27^{o-t}	42.13^{p-u}	42.67^{o-s}	1.170	-0.32	0.940
SCS-1	17.93^{Az}	16.53^{B}	22.50^{pqr}	22.87^{pq}	7.81	26.5	27.71	32.07^{ABz}	29.80^{B}	38.80^{wv}	41.53^{q-v}	7.070	23.20	28.25
PI423958	13.33^{C}	9.670^{D}	23.27^{op}	25.93^{lm}	27.4	58.4	62.71	22.13^{C}	14.33^{D}	39.27^{t-w}	41.87^{q-v}	35.26	63.51	65.77
Mean	**23.63^{c}**	**20.37^{d}**	**25.98^{b}**	**30.77^{a}**	**11.7**	**21.2**	**32.5**	**44.40^{c}**	**38.43^{d}**	**49.71^{b}**	**55.66^{a}**	**11.5**	**21.8**	**29.3**
	CV(a)= 2.0		**CV(b) = 2.67**					**CV(a)= 3.11**		**CV(b)=3.91**				

Where, L= Lime treated alone, P= Phosphorus treated 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.

4.4.3. Above ground biomass

The highest aboveground dry 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 11); while the lowest aboveground dry biomass yield (1.43t ha^{-1}) was recorded on genotype PI423958 under the control main plots, which was lower by about 393% of aboveground dry biomass weight of the genotype that produced the highest aboveground dry biomass yield (Table 11). However, genotypes: JM-HAR/DAV-15-SA, H-7, JM-CLK/CRFD-15-SA, JM-ALM/H3-15-SC-1, SCS-1 and JM-CLK/G99-15-SB were statistically at par with genotype PI423958 under the control and lime treated alone, except JM-CLK/CRFD-15-SA and JM-ALM/H3-15-SC-1 genotypes were only under the control plots (Table 11).

The performance of HAWASSA-04 variety and genotype JM-DAV/PR142-15-SA was relatively higher at the control soil condition, compared to their performance at lime and P amended soil conditions. 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 above ground dry biomass production, which is supported by the earlier works of Liang *et al*. (2013) who reported that the large difference in biomass production among two different soybean genotypes, in which P-efficient soybean genotype (HN89) adapted better to the acidic soil conditions than the P-inefficient genotype (HN112), and showed greater biomass, especially under applied phosphorus.

Genotypes responded to phosphorus and liming amendment, which might be due to either an improved rate of P supply to the soil or an improved ability of the plant to absorb P, when Al toxicity has been eliminated, and enhanced the vegetative growth of soybean genotypes, which resulted in increased dry biomass yield. Genotype PI423958 showed the highest decrease of 66.22%, while genotype JM-H3/SCS-15-SG showed low decrease of -1.3% for above ground biomass under control main plot amendments, which showed that the performance variation of genotypes to acidic soil. Temesgen *et al*. (2017) reported that barley above ground biomass was reduced in control plots by 38.2% compared with P treated plots. The authors also reported that the highest dry biomass of barley were recorded on lime amended soil with 2.2 t ha^{-1} and 30 kg P ha^{-1} than separate application of lime and phosphorus. Phiri *et al*., (2016) reported that application of 25 kg ha^{-1} P and 35 kg ha^{-1} P increased the soybean dry biomass yields by 54 and 70%, respectively, over the control plots. In line with this result, Workneh (2013) also reported significant increase in straw yield of soybean by 16.3%, due to soil liming at the rate of 2.6 t ha^{-1}.

4.4.4. Grain yield

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 and lime and genotype PI567046A with respective mean grain yield of 1534.5 and 1943.9 kg ha^{-1} under P alone and lime alone soil conditions, respectively, and HAWASSA-04 variety with mean grain yield of 2120 kg ha^{-1} under lime alone soil condition gave the highest grain yield (Table 11). The highest grain yield (2120 kg ha^{-1}) obtained from this result is still below the national average (2217 kg/ha), but more than the productivity in the study area or Mettu (1300kg/ha), which shows that the yield improvement failed to meet the national average, which might indicates that one time application and short term effects of lime and P may not be sufficient to get the desired level of yield improvement. Similarly, the yield may fail below national average due to high rain fall (300mm) during the month of lime application which might cause removal of applied lime which resulting no more improvement of soil pH and other important soil chemical properties. From the soil results, the lime requirements of soil might not adequate to correct soil pH to optimum level, this might be the soil of study site has high buffering capacity and the lime requirement should be considered to increase yield to the average level.

HAWASSA-04 variety and genotype BRS268 produced the highest grain yield at the control soil condition, 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. This is supported by the work of Nigussie (2012) who reported a large difference in yield performance among different bean genotypes. Uguru *et al*. (2012*)* also reported performance difference among soybean genotypes, as the best genotype at pH 5.87 have grain yield differences of 0.32 t/ha with the average grain yield.

Genotype PI423958 showed high decrease (73.3%) from the control plots relative to its performance under both P and lime, while genotype BRS268 showed low decrease (-15.4%); relative to its performance under lime alone amendments, which might be due to the genetic difference of the genotypes in response to the amendments. 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 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. Temasgen *et al*. (2017) also reported that the highest barley grain yield was obtained under the application of 2.2 t/ha lime and 30 kg/ha P than their separate form.

Similarly, Mesfin *et al.* (2014) reported that the highest seed yield (1488.4 kg ha^{-1}) of common bean was obtained from the combined application of 30 kg ha^{-1} P_2O_5 and 0.4 t ha^{-1} limes. Verde *et al*. (2013) also reported significant yield increment of soybean under combined application of both lime with P-fertilizer, over the application of lime or P alone. Aziz *et al*. (2016) reported that P applications at the rate of 22.5 and 45.0 kg ha^{-1} P_2O_5 increased grain yield by 33.9 and 35.4%, respectively, over the unfertilized control in Ghana. Achalu *et al*. (2012) also reported increased crop yield in response to the application of lime, which might be attributed to the neutralization of Al^{3+}, supply of $Ca^{2+}$and increasing availability of some plant nutrients like P.

Table 11. 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}	1287.7^{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.

4.4.5. Hundred Seed weight (g)

Genotype PI423958 gave the highest hundred seed weight (19.88g) (Table 12), whereas the lowest hundred seed weight (10.80 and 11.79g) was recorded on genotypes: PI567046A and H-7, respectively (Table 12). The genotype (PI423958) produced the highest hundred seed weight showed seed weight increase of 84.1% over the lowest genotype. In agreement with this result, Habtamu (2017) reported significant difference among soybean genotypes for hundred seed weight, in which the highest hundred seed weight was produced by BFS 39 genotype and the lowest hundred seed weight was recorded from Roba.

Among the amendments, the highest hundred seed weight (15.20 and 15.14g) was obtained from combined application of lime with P, and P treated alone, respectively (Table 12). Statistically, these two amendments were at par and significantly ($p<0.01$) superior to the control and lime alone plots; while the lowest hundred seed weight (13.66 and 14.34g) was obtained from lime treated alone and the control plots, respectively (Table 12). Application of lime alone and the control plot were statistically at par, which indicates P application has more contribution to the increase in hundred seed weight than lime application (Table 12).

The combined application of lime with P, and P alone increased hundred seed weight by 11.27 and 10.83%, respectively relative to the control plots, which might be due to the importance of P in improving phosphorus nutrition of the crops, and phosphorus plays important role in seed development and increase in seed size. In agreement with this result Workneh (2013) and Wadjrano and Taufiq (2016) reported non-significant effect of liming on hundred seed weight of soybean. Similarly, Bambara and Ndakidemi (2010) also reported non- significant effect of liming on hundred seed weight of common bean. According to Temasgen *et al.* (2017), the application of phosphorus at the rate of 30kg/ha increased hundred seed weight of barley by 4.6% over the control treatment (no phosphorus).

Table 12. Main effects of amendments and genotypes on hundred seed weight of soybean genotypes under acid soil condition in field at Metu during 2017/18 main cropping season

Genotypes			HSW(g)	
PI423958			19.88[a]	
JMALM/PR142-15-SC			16.14[b]	
HAWASSA-04			16.11[b]	
JM-H3/SCS-15-SG			15.86[b]	
JM-HAR/DAV-15-SA			15.35[bc]	
JM-PR142/H3-15-SB			15.05[bc]	
BRS268			14.28[cd]	
JM-CLK/CRFD-15-SA			14.22[cd]	
JM-ALM/H3-15-SC-1			14.17[cd]	
JM-CLK/G99-15-SB			13.95[cd]	
JM-CLK/G99-15-SC			13.94[cd]	
JM-DAV/PR142-15-SA			13.78[cd]	
SCS-1			13.43[d]	
H-7			11.79[e]	
PI567046A			10.80[e]	
Mean			**14.58**	
CV(a)= 13.46			**CV(b)= 11.54**	
Amendments	**L**	**C**	**P**	**LP**
Mean of HSW(g)	13.66[b]	14.34[b]	15.14[a]	15.20[a]

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

4.5. 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 (Table 13 and 14). The tolerance and susceptibility rating of specific entries depended upon the particular criterion (based on observed characters) used to denote their tolerance and susceptibility. Genotype PI567046A and variety HAWASSA-04 produced the highest tolerance values, and grain yield, and hence might be considered the tolerant genotypes (Table 15); while genotype PI423958 was found the most susceptible genotype for yield and yield components i.e., grain yield, above ground biomass, number of pods and seeds per plant (Table 14). HAWASSA-04 was the most tolerant variety, and produced the highest value of tolerance index for shoot dry weights (Table 13). In line with these findings, Kuswantoro (2015) reported significant difference among soybean genotypes in which MLGG 0343 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.

Genotypes: PI567046A and BRS268, and variety HAWASSA-04 produced the highest tolerance index and mean productivity value for above ground biomass, which indicates these genotypes are tolerant among the others (Table 13 and 15), and the most susceptible genotype was SCS1, which showed high susceptibility value for number of nodules, shoot and root dry weight. Similarly, for plant height, number of pods and seeds per plant genotype PI567046A was the most tolerant and produced the highest tolerance index and mean productivity values (Table 13 and 15). Generally, the results shown in ASAI of shoot dry weight, yield, plant height, above ground biomass, number of seeds and pods per plant showed that genotype PI567046A and HAWASSA-04 variety gave the highest ASAI and mean productivity value, and low susceptibility value and these genotypes, were statistically non-significant, and hence, considered as the most tolerant genotypes for most of the tested traits (Table13, 14 and 15). Liang *et al.* (2013) reported that acid tolerance of P efficient soybean genotype (HN89) than the P-inefficient genotype (HN112), and the P-efficient genotype showed greater value of tolerance for more than five characters, under both high and low P conditions.

Genotype PI567046A and HAWASSA-04 variety are the top performing genotypes for most of the studied parameters across the different amendments, which might shows the tolerance of these genotypes than the rest. This result is in line with the findings of Kuswantoro (2015), who reported the highest ASAI on seven characters i.e., on root dry weight, shoot dry weight, number of lateral root, nodule dry weight, number of nodules and root length in one soybean genotype, where the genotypic difference was found for tolerance and for its response to soil acidity. Foy *et al.* (1993) also reported genotype G4AB was considered as adaptive to acid soil, among other tested genotypes based on the observed characters. Similar results were also reported by Rao (2001) and Rangel *et al.* (2007) on common bean genotypes for tolerance to acid soils.

Table 13. 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}	1.24d^{ef}	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 14. 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

Table 15. Mean productivity of soybean genotypes for different traits on acidic soil condition

Genotypes	YLD	PHT	NSPP	NPPP	AGB	SDW	RDW	NN
PI567046A	1559.92^{b}	78.23^{a}	76.03^{a}	37.52^{a}	5.143^{a}	4.46^{h}	0.68^{gh}	38.43^{e}
HAWASSA-04	1800.15^{a}	56.50^{b}	50.20^{cd}	28.47^{c}	5.083^{a}	7.89^{a}	0.933^{c}	47.33^{c}
PI423958	1254.93^{e}	33.77^{i}	28.10^{j}	17.80^{k}	2.83^{e}	6.26^{de}	0.65^{hi}	57.23^{a}
JMALM/PR142-15-SC	1476.99^{c}	48.87^{d}	44.97^{f}	22.73^{j}	4.21^{b}	6.81^{c}	1.063^{a}	42.20^{d}
JM-HAR/DAV-15-SA	1260.66^{de}	42.77^{g}	51.40^{c}	26.77^{d}	4.21^{b}	7.09^{b}	0.730^{f}	41.77^{d}
JM-PR142/H3-15-SB	1334.24^{d}	53.33^{c}	49.23^{d}	25.47^{ef}	4.91^{a}	6.15^{def}	0.997^{b}	52.80^{b}
H-7	1152.49^{f}	34.83^{i}	48.33^{de}	23.27^{hi}	3.17^{cde}	6.27^{d}	0.713^{fg}	42.37^{d}
JM-H3/SCS-15-SG	1262.59^{de}	53.23^{c}	47.10^{e}	24.50^{fg}	4.20^{b}	5.98^{fg}	0.820^{e}	34.40^{h}
JM-CLK/CRFD-15-SA	1025.93^{g}	48.33^{de}	40.93^{h}	23.03^{hi}	3.67^{bc}	4.27^{i}	0.970^{bc}	34.47^{h}
BRS268	1320.84^{de}	52.80^{c}	58.13b	32.80^{b}	4.94^{a}	6.74^{c}	1.013^{ab}	33.43^{h}
JM-ALM/H3-15-SC-1	926.520^{h}	47.70^{de}	41.23^{gh}	23.97^{gh}	3.54^{cd}	3.70^{j}	0.873^{d}	26.73^{i}
SCS-1	842.400^{i}	46.67^{ef}	35.67^{i}	19.70^{j}	3.043^{de}	3.70^{j}	0.763^{f}	35.80^{fg}
JM-CLK/G99-15-SC	970.62^{gh}	48.73^{d}	48.97^{de}	28.60^{c}	4.10^{b}	6.26^{de}	0.600^{i}	35.60^{g}
JM-CLK/G99-15-SB	939.02^{gh}	45.27^{f}	42.97^{g}	23.40^{hi}	2.89^{e}	5.87^{g}	0.510^{j}	36.73^{f}
JM-DAV/PR142-15-SA	987.70^{gh}	39.43^{h}	42.47^{gh}	25.50^{e}	3.08^{de}	6.037^{efg}	0.740^{f}	46.33^{c}
Grand Mean	1207.6	48.69	47.049	25.56	3.935	5.82	0.803	40.37
LSD	74.705	1.792	1.9679	0.9683	0.5464	0.1805	0.0511	1.067
CV	3.698	2.2	2.5	2.26	8.30	1.853	3.799	1.58

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.

4.6. Correlation Analysis

4.6.1. Correlation of root and nodulations with yield and yield components

Grain yield was significantly ($P\leq 0.01$) and positively correlated with all root parameters viz., root dry weight, root fresh weight and root volume and also with all nodule parameters viz., number of nodule, nodule dry and fresh weight (Table 16). The significant and positive correlations of grain yield with the rooting parameters viz., root volume, root dry and fresh weight, under acid soil condition (hydrogen and alumunium toxicity) indicates the importance of the root parameters for low P tolerance or acid soil tolerance. This also implies that selection for low P or acid soil tolerance should consider these important root parameters. In line with this result 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.

Similarly, yield components viz., number of pods per plant, number of seeds per plant and above ground dry biomass yield were highly significant ($P\leq 0.01$) and positively correlated with the rooting parameters viz., root volume, root dry and fresh weight, under acid soil conditions (Table 16). This also indicates the importance of the rooting traits for water and nutrient up take on acidic soil, especially phosphorus that would have increased the intensity of photosynthesis, nitrogen fixation, flowering, seed formation and fruiting, which directly contributed for pods and seed number increment per plant. In line with this result Abush *et al*. (2017) reported positive correlation of rooting parameters with yield components of soybean.

4.6.2. Correlations of yield components and growth parameters with grain yields

Grain yield is the product of its yield components, such as number of pods per plant, number of seeds per plant, hundred seeds weight and above ground dry biomass were highly significant and positively correlated with its grain yield (Table 16). However, grain yield was strongly correlated with above ground biomass (r=0.82), followed by number of pods (r=0.70) and number of seeds per plant (r=0.71) among yield parameters, respectively. Other 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 seeds per plant, and greatly contributed to increase in grain yield of soybean.

Growth parameters, such as shoot fresh and dry weight, and plant height were positively and significantly ($P<0.01$) associated with grain yield of soybean (Table 16). However, the grain yield was also strongly correlated with shoot dry weight (r=0.76) and shoot fresh weight (r=0.81). There was also highly significant and positive associations of above ground biomass with number of seeds and pods per plant (Table 16), in which above ground biomass was strongly correlated with number of seeds per plant (r=0.84) and number of pods per plant (r=0.83), respectively. Similar to this finding Temasgen *et al*. (2017) reported positive and sig nificant correlation of biomass yield with thousand seeds weight and number of seeds per spike of barley. Similarly, the number of seeds per plant was strongly correlated with number of pods per plant (r=0.94) (Table 16). On the other hand, negative and significant correlation coefficients were observed between hundred seeds weight and number of seeds per plant (Table 16). The highly significant and negative correlation of hundred seeds weight with number of seeds per plant in this study might be due to the competitiveness of the seeds for nutrition to fulfill the seeds.

Table 16. Correlations of growth, root, nodulation traits with some of yield and yield related traits at both soil amended condition

	YLD	PHT	NSPP	NPPP	AGB	NDW	SDW	NFW	RV	SFW	RDW	RFW	NN	HSW
YLD	1													
PHT	0.63**	1												
NSPP	0.71**	0.80**	1											
NPPP	0.70**	0.75**	0.94**	1										
AGB	0.82**	0.74**	0.84**	0.83**	1									
NDW	0.64**	0.12^{ns}	0.26**	0.28**	0.40**	1								
SDW	0.76**	0.30**	0.46**	0.51**	0.60**	0.83**	1							
NFW	0.62**	0.14ns	0.30**	0.32**	0.42**	0.94**	0.83**	1						
RV	0.59**	0.47**	0.35**	0.38**	0.61**	0.34**	0.47**	0.34**	1					
SFW	0.81**	0.37**	0.53**	0.57**	0.66**	0.78**	0.97**	0.79**	0.55**	1				
RDW	0.61**	0.44**	0.38**	0.42**	0.64**	0.30**	0.51**	0.30**	0.82**	0.60**	1			
RFW	0.65**	0.49**	0.39**	0.41**	0.65**	0.35**	0.53**	0.35**	0.86**	0.61**	0.91**	1		
NN	0.64**	0.17*	0.26**	0.32**	0.41**	0.82**	0.76**	0.83**	0.52**	0.78**	0.48**	0.51**	1	
HSW	0.25**	-0.18*	-0.21**	-0.14^{ns}	0.12^{ns}	0.44**	0.34**	0.41**	0.27**	0.32**	0.22**	0.26**	0.40**	1

Where, NPPP: Number of pod per plant, NSPP: Number of seed 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.HSW: Hundred seed weight, *: Correlation is significant at the 0.05 level, and **: Correlation is significant at the 0.01 level.

4.7. Selected Soil Physicochemical Properties Prior to Planting

The textural class of the soil was clayey, with sand, silt and clay proportions of 38, 13 and 49 %, respectively. Rienke and Joke (2005) reported that as soybean gave high yield in loamy textured soil, however it can also grow better on clay soils. Similarly, the bulk density was 1.13 g cm^{-3} (Table 17). The values of bulk densities observed on the soil of the experimental field is somewhat lower than the commonly quoted average values for mineral soils world-wide which is 1.34 g cm^{-3} bulk density. Following the rating of pH of < 4.5 as extremely acidic, 4.5-5.0 very strongly acidic, 5.1-5.5 strongly acidic, 5.6-6.0 moderately acidic and 6.1-6.5 slightly acidic of soil status as indicated by (Foth and Ellis, 1997), the soil used for this study falls under the extremely acidic (pH 4.4) class indicating that the possibility of Al toxicity and deficiency of certain plant nutrients.

The optimum pH range for legumes is generally reported to be between 6.6 and 7.5 (Johnston, 2004). Soybean has been found to do well in pH values of 5.5 – 7.0 and any pH below these values will affect its growth and needs amendments (Ferguson *et al*., 2006). This indicates that soybean growth and yield is limited by low pH soil. Therefore, soil liming up to pH 6.5 to 7.0 is required for optimum yield and plant growth in soybean (Havlin *et al*., 1999). Exchangeable acidity of the experimental soil was 2.72 cmol kg^{-1}, which indicates that the toxicity of some metal elements might affect growth of crops (Landon, 1991, Haynes and Mokolobate, 2001). According to Landon's (1991) rating the CEC value of the soil estimated by the ammonium acetate at pH 7 was medium (18.75 cmol (+) kg^{-1}), indicating that the soil is less fertile. According to FAO (2006), the experimental soil has moderate exchangeable K^+, low exchangeable Ca^{2+} and moderate exchangeable Mg^{2+} for several plants signifying that it requires external application of these nutrients as per the recommendations for the crop grown.

Table 17. Physicochemical properties of the experimental soil prior to cropping

Parameters	Value
Particle size distribution	
Clay (%)	49.00
Sand (%)	38.00
Silt (%)	13.00
Textural class	Clayey
pH(H_2O)	4.400
Bulk density (g/ cm^{-3})	1.130
Exchangeable acidity (cmol(+)/kg)	2.720
Exchangeable Al (cmol(+)/kg)	1.460
Organic carbon (%)	2.210
CEC (cmol (+) kg^{-1})	18.75
Acid saturation (%)	15.00
Total N (%)	0.210
Available P(BrayII)(mg kg^{-1})	2.950
Exchangeable K (cmol (+) kg^{-1})	0.330
Exchangeable Na (cmol(+) kg^{-1})	0.017
Exchangeable Ca (cmol(+) kg^{-1})	3.550
Exchangeable Mg (cmol(+) kg^{-1})	1.380
Total exchangeable bases (cmol(+)kg^{-1})	5.280
Base saturation (%)	28.16
Lime requirement (kg of $CaCO_3$ ha^{-1})	3,457.8

According to Landon (1991), available (Bray-II) soil P level of less than 5 mg kg^{-1} was considered as low; 5-15 mg kg^{-1} as medium, and greater than 15 mg kg^{-1} as high. Thus, the available P being 2.95 mg kg^{-1} P (Table 17) was below the critical level for most crops. It is the worst P level, which is far below the critical level of P for most crops. Similarly, Landon (1991) considered Total Nitrogen (TN) > 1% as very high, 0.5 to 1% as high, 0.2 to 0.5% as medium, 0.1 to 0.2% as low and < 0.1% as very low N, and hence the soil of the experimental plot might be regarded as having medium TN. Similarly, the Organic Carbon (OC) content of the soil was also low in accordance with Landon (1991) who categorized OC content as very low (< 2%), low (2- 4%), medium (4-10%), high (10-20%). Organic carbon (OC) in soils influence physical, chemical and biological properties of soils, such as soil structure, water retention, nutrient contents and retention and micro - biological life and activities in the soil.

4.8. Effect of Main Plot Treatments on Soil Chemical Properties after Harvesting

4.8.1. Soil pH and exchangeable acidity (Al^{+} + H^{+})

Combined application of P and lime increased soil pH from initial (4.4) to 4.9 (Table 18), which is equivalent to change in the soil reaction from extremely acidic to very strongly acidic. There was 0.5 pH increment, as compared to initial soil pH (4.4). Application of lime alone also showed the change in soil pH from 4.4 (initial) to 4.73. This indicated that when lime is added to acid soils that contain high $Al^{3+}$and H^{+} concentrations, it dissociates into Ca^{2+} and OH^{-} ions. The hydroxyl ions will react with hydrogen and Al^{3+} ions forming Al^{3+} hydroxide and water; thereby, increasing soil pH in the soil solution. Increase in the soil pH over the control, in response to the application of lime alone or combined with P was also reported by Temasgen *et al*. (2017). Mesfin *et al*. (2014) also reported that the application of 0.4 t ha^{-1} lime increased soil pH by 7%, relative to unlimed control. The present findings is also in agreement with Murata *et al*. (2002) who reported that application of lime at the rate of 2 t ha $^{-1}$ significantly increased top soil pH values from 4.6 to 6.0.

Exchangeable acidity and Al contents of the soil were decreased in response to the application of lime and P in combinations, as well as, the application of lime and P, separately (Table 18). The highest exchangeable Al (1.38 cmol (+)/kg) and acidity (2.41 cmol (+)/kg) was recorded on the control plots. Application of lime alone reduced soil exchangeable acidity, and Al to 1.52 and 0.92 (cmol (+)/kg), which was 2.72 and 1.46 (cmol (+)/kg), respectively, at the beginning of the experiment (Table 18). The decrease in the exchangeable acidity and alumunium was about 44.1 and 36.3%, as a result of lime amendment alone, compared to at the start of the experiments. This is might be due to increased replacement of Al by Ca in the exchange site and subsequent precipitation of Al, as $Al(OH)_3$, due to liming of the soil (Fageria and Baligar, 2008). Application of P alone also resulted in decreased exchangeable Al and acidity (Table 18), which might be P counteracted Al toxicity by precipitating exchangeable Al^{3+} as $AlPO_4$ (Temasgen *et al*., 2017), which could be the reason why high rate of phosphate fertilizer applications on acidic soils to overcome the toxic effects of Al, thereby, improve plant growth. The decrease in exchangeable Al and acidity, in response to the application of P alone might also be due to the formation of hydroxyl-Al phosphates (Havlin *et al*., 1999).

Table 18. The main effects of lime and Phosphorus and their combined on soil pH, exchangeable acidity and exchangeable Al of the soil in field during 2017/18 cropping season

Main plot treatments Applied P &L(kg ha^{-1})	pH(H_2O)	Exchangeable Acidity(H+ Al) (cmol(+) kg^{-1})	Exchangeable Al (cmol(+) kg^{-1})
Control (no P and L)	4.48	2.41	1.38
Lime only = 3,457.8	4.73	1.52	0.93
Phosphorus only =20	4.65	1.66	0.97
Both L 3,457.8 &20P	4.90	1.63	0.92

P=phosphorus, L=lime, Al= alumunium H=hydrogen

4.8.2. Soil organic carbon, total nitrogen, and available phosphorus

Lime slightly increased soil OC from 2.2 to 2.45 (Table 19). The increment of soil OC in response to lime alone was about 11.36% over the control (no lime applied soil). The highest soil OC (2.56%) content was observed under combined application of lime and P, which was about 16.36% increment over the control plots. The increment of soil OC contents due lime and P application, (sole or combined) might be associated with the improvement of soil conditions, which might be enhanced biomass production, proliferation of soil microbial and their activity in the soil. Amba *et al*. (2011) also attributed increase in soil organic carbon to the dropping of leaves, which added OC to the soil.

Total nitrogen (TN) contents of the experimental soil were also increased to a much lesser extent due to the application of P and lime altogether or independently (Table 19). This slight increment indicates that one-time application and short-term effects of lime and P might not be sufficient to affect the TN of the soils. Total nitrogen increment was found from the initial content (0.21) to 0.24, after completion of the trial in response to the application of lime alone or along with P. This slight improvement in TN could be due to the increased soil pH that might have encouraged microbial activity in the soil, and thus, increased mineralization of N from OM (Roosevelt, 2004).

Table 19. Main effects of lime, phosphorus and their combined on soil pH, organic carbon, total nitrogen and available phosphorus in field at Mettu during 2017/18 cropping season

Main plot treatments	Soil organic carbon, total nitrogen and available phosphorus		
Applied P &Lime(kg ha^{-1})	Organic carbon (%)	Total nitrogen (%)	Available P(mg kg^{-1}) Bray II
Control (no P and Lime)	2.22	0.22	2.98
Lime only = 3,457.8	2.45	0.24	4.39
Phosphorus only =20	2.42	0.23	5.90
Both lime 3,457.8 &20P	2.56	0.24	6.89

P: phosphorus, L: lime

Available P extracted by Bray II methods was higher in all lime and P treated plots than that of untreated plots (Table 19). The highest available P of 6.89 mg kg^{-1} was obtained under the combined application of lime and P, which was an about 131.2% increment over the control plots. This substantial increase in available P might be as a result of quick action of lime in improving soil acidity, and hence, increased availability of P (Kisinyo, 2016) and the effect of P fertilizer in increasing P in the soil solution (Tisdale *et al*., 1990). Application of lime alone also increased available P of the soil from 2.95 to 4.39 mg kg^{-1}, which was about 47.32% increment over the control plots (Table 19). This might be due to the applied lime contributed in the release of some amount of fixed P to the soil, which will be available for the crop.

Liming of acidic soils could increase soil pH, which enhances the release of phosphate ions fixed by Al and Fe ions into the soil solution. However, application of lime alone could not help in increasing available P, like that of the combined application of lime and P. This indicates that the deficiency of P cannot be replaced by lime. The observed increment in available P was probably related to the decrease in reactive Al and also increase in surface negative charge resulting from the increased soil pH (Temasgen *et al*., 2017). Achalu *et al*. (2012) also reported that the deficiency of P could be corrected thought liming of acid soil to increase the pH more than 6. After harvesting the soybean, available P increased from 2.95 to 5.90 mg kg^{-1} in response to the application of phosphorus alone, which was about 97.98% increase over the control plots. This might be due to the reduced adsorption sites, as a result of the added P (Anetor and Akinrinde, 2006).

4.8.3. Soil exchangeable bases (Ca, Mg, Na and K) and cation exchange capacity (CEC)

The CEC values of the experimental soil were increased to some extent with the application of lime and P, independently or in combined forms (Table 20).The CEC of experimental soil was increased from 18.75 to 21.04 cmol (+) kg^{-1}, due to the application of lime alone, which was about 11.38% of CEC increase over the control main plots. The highest CEC (21.16 and 21.04 cmol (+) kg^{-1}) was recorded for soils from plots treated with combined application of lime with P, and lime alone, respectively. This might be due to the improved soil conditions, such as soil pH, increased soil OM and reduction of exchangeable acidity, which in turn increased the exchange sites of the soil. In line with this result, the findings of Buni (2015) reported the increase in CEC after the application of lime (33.34 cmol (+) kg^{-1}) over unlimed or control plot (19.18 cmol (+) kg^{-1}).

Liming can increase phosphate availability by stimulating mineralization of soil organic phosphorus. Additions of P alone also increased CEC of the soil, to a lower extent compared to lime ($CaCO_3$). The CEC values of the soil increased from 18.75 to 19.30 cmol (+) kg^{-1} under P applied alone (Table 20). Lime addition alone increased the CEC of the soil by 11.38% over the control plots, whereas the CEC increase due to the application of P alone was higher only by 2.2 % over the control plot. This indicated that lime was more efficient in increasing CEC of the soil than phosphorus. The observed CEC increments due to P addition alone was probably caused by decrease in the positive charge of the soil exchange site, as a result of phosphate adsorption on hydroxy–Al (Bohn *et al*., 2001).

Table 20. Main effects of lime and P and their combined on exchangeable cations and CEC in field at Mettu during 2017/18 cropping season

Main plot treatments	Exchangeable cations and CEC (cmol(+)/kg^{-1})				
Applied P &L(kg ha^{-1})	Ca	Mg	K	Na	CEC
Control (no P and L)	3.81	1.40	0.40	3.10	18.89
Lime only = 3,457.8	5.39	1.59	0.67	ND	21.04
Phosphorus only =20	4.28	1.42	0.41	3.60	19.30
Both L 3,457.8 &20P	5.95	1.62	0.69	ND	21.16

P: phosphorus, L: lime, CEC: Cation exchange capacity, ND: Not detected

Exchangeable calcium content of the soil was increased in response to the application of lime and P, separately or in combined form. Application of lime alone increased soil exchangeable Ca by 41.47 % above the control. The maximum exchangeable Ca value of 5.95 cmol $_{(+)}$ kg^{-1} was obtained from combined application of P and lime, followed by 5.39 and 4.284 cmol (+) kg^{-1} for separate applications lime and P, respectively (Table 20). An increase of 56.16% exchangeable Ca, above the control, was recorded on soil samples collected from plots treated with combined application of lime and P (Table 20). Probably, this higher exchangeable Ca^{2+}content from the lime might be attributed to the release of Ca^{2+} ions from lime through its dissolution and replacement of H^+ and Al^{3+} from the soil solution and soil exchange complex.

The amount of exchangeable Ca in the soil showed a slight increase with the addition of P alone, compared to the control plots. This indicate that P application can neutralize the Al saturation in the soil by releasing Ca i.e. counteracted Al toxicity through precipitating exchangeable Al^{3+}, as $AlPO_4$. Caires *et al*. (2006) reported increased exchangeable Ca, following the application of lime alone, and along with P. Generally, this indicates that combined application of lime and P improved the exchangeable Ca status of the soil, rather than applying, either lime or P fertilizer alone. Several authors reported that combined application of lime alone, lime with P, and also lime with OM, such as manure and compost improved the soil chemical properties: pH, exchangeable Ca, and microbial activity (Achalu *et al*., 2012 and Kisinyo *et al*., 2016).

The amount of exchangeable Mg in the soil showed slight increase with the application of lime; however the Mg content of the soil was not affected by the application of P fertilizer (Table 20). The increase exchangeable soil Mg, due to lime application was 1.4 cmol (+)/kg^{-1} (control) to 1.59 cmol (+)/kg^{-1} (lime alone), which was 13.57% over the control (Table 20). This indicates that lime increases the retention of Mg, due to the increase in CEC (resulting from the increase in pH). Similarly, exchangeable K content of the soil was slightly (0.4 to 0.67) improved with amendment of lime, while it did not respond to P application (Table 20). This might be due to liming acid soils increase soil pH and improve soil K with mineralization of soil from clay particles and enhance retention of K^+ and thereby decrease K^+ leaching. Liming increases K^+ retention in soils by replacing Al^{3+} on the exchange sites with

Ca^{2+}, allowing K^+ to compete better for exchange sites and increasing cation exchange capacit y (Fageria and Baligar, 2008).

Rahman *et al*. (2008) found increased Mg in the soil as a result of applied lime, either alone or combined with P and attributed to the increase in improved soil pH, as was observed in this study. In contradict to this findings of Achalu *et al*. (2012) reported decrease in Mg^{2+} with the application of agricultural lime, which might be due to competitive exchange between the Ca^{2+} and Mg^{2+} ions in the sorption complex, in which Ca dominates and soil displaces Mg^{2+} ion from exchange site. As might be expected on such acidic soil, the exchangeable Na, which was, generally, low at the start of the experiment was removed from the soil, as a result of the applications of lime and increased under lime untreated plots (Table 20). This might be due to the replacement of sodium with calcium, and then leached the sodium out.

5. CONCLUSION AND RECOMMENDATION

Soybean (*Glycine max* L.) is one of the very important leguminous and oil crops, and grown for its oil and protein source. Soil acidity has become a great threat in food production through limiting the production potential of the crops because of low availability of nutrients, basic cations and excess hydrogen (H^+) and aluminium (Al^{3+}) 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, mainly due to their low purchasing capacity, low availability of lime, high cost of mineral fertilizers and lime transportation, has kept lime and mineral fertilizers from reaching smallholder farmer's fields.

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 low P soil, and soybean genotypes that respond to optimum lime and P management and to evaluate the interaction effect of liming and phosphorus on growth, yield and yield components of soybean genotypes on acidic Nitisol soil of Mettu condition. The treatments were laid down in split plot design with three replications. The four types of soil amendments i.e. control, lime alone (3457.8 kg ha^{-1}), phosphorus alone (20 kg ha^{-1}) and both lime and phosphorus (3457.8 +20 kg ha^{-1}) were applied as main plots, where as fifteen soybean genotypes were assigned to sub-plot treatments. The physical and chemical properties of soil were analyzed before planting and after harvest.

Results indicated that, the existence of significant genotype x amendment interactions for all root, 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 , although they are among the traits that receive little attention in most soybean research for acid tolerance. These findings also suggested that soybean selection experiments for low pH tolerance would be effective to improve grain yield and the essential agronomic traits of soybean genotypes. Future studies would be necessary to investigate the variation of these genotypes under both amendments and also as this study was done for one season at one location, the experiment has to be repeated over locations and years under different soil type in the study area to reach at a conclusive recommendation.

The main effect of lime and phosphorus, and also their interaction effects significantly influenced plant height, above ground dry biomass yield and yield, root dry and fresh weight, number of nodule per plant, nodule dry and fresh weigh, shoot fresh and dry weight, number of pods and seeds per plant and also soil pH and exchangeable acidity. Combined application of lime and phosphorus significantly improved the soil properties and theses improvements have resulted in increased grain yield and yield related parameters of soybean grown on the acidic Nitisol of Mettu. The combination of lime (3,457.8 kg ha^{-1}) with P (20 kg/ha) 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 highest grain yield (2120 kg ha-1) was obtained under combination of 20 kg P ha^{-1} and 3,457.8 kg lime ha^{-1} from HAWASSA-04 variety.

Combining lime (3,457.8 kg ha^{-1}) with Phosphorus (20 kg ha^{-1}) was the best practice and reduced exchangeable acidity from initial (2.72 cmol (+) mg/kg) to 1.63 cmol (+) mg/kg. 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 this genotype 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. Also further study should be conducted by further introducing of additional genotypes from abroad to determine their response to acid soil and to optimum lime and phosphorus fertilizers which can maximize the productivity of the crop and reduce soil acidity problem in the study area.

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7. APPENDEXIS

Appendix Table 1. Analysis of variance for plant height of soybean genotypes

Source	DF	MS	F	P
Block	2	9.87		
Amendment	3	1225.4	652.41**	0.01
Error (a)	6	3.50		
Genotypes	14	1508.67	803.22**	0.01
Amendment*genotypes	42	13.53	7.21**	0.01
Error(b)	112	1.878		
Corrected Total	179			
	CV(b): 2.79			

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 2. Analysis of variance for number of pod per plant of soybean genotypes

Source	DF	MS	F	P
Block	2	2.57		
Amendment	3	860.89	1893.56**	0.01
Error (a)	6	0.25		
Genotypes	14	325.78	716.57**	0.01
Amendments*genotypes	42	36.16	79.54**	0.01
Error(b)	112	0.45		
Corrected Total	179			
Grand mean	**25.2**	**CV(b): 2.67**		

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 3. Analysis of variance for number of nodule per plant of soybean genotype

Source	DF	MS	F	P
Block	2	0.35		
Amendment	3	5523.64	6222.51**	0.01
Error(a)	6	0.15		
Genotypes	14	675.59	761.07**	0.01
Amendment*genotypes	42	113.92	128.33**	0.01
Error(b)	112	0.88		
Total	179			
	CV(b) : 2.37			

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table: 4. Analysis of variance for number of seed per plant of soybean genotypes

Source	DF	MS	F	P
Block	2	5.137		
Amendment	3	2437.25	718.89**	0.01
Error(a)	6	2.149		
Genotypes	14	1601.85	472.49**	0.01
Amendment*genotypes	42	145.08	42.79**	0.01
Error(b)	112	3.39		
Total	179			
CV(b):3.91				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 5. Analysis of variance for above ground biomass of soybean genotypes

Source	DF	MS	F	P
Block	2	0.998		
Amendment	3	29.185	138.35**	0.01
Error(a)	6	0.5436		
Genotypes	14	9.815	46.53**	0.01
Amendment*genotypes	42	1.426	6.72**	0.01
Error(b)	112	0.21		
Total	179			
CV(b)=11.68				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 6. Analysis of variance for yield of soybean genotypes

Source	DF	MS	F	P
Block	2	5071.69		
Amendment	3	3438596.14	683.01**	0.01
Error(a)	6	15535.96		
Genotypes	14	999270.44	198.48**	0.01
Amendment*genotypes	42	136675.08	27.15**	0.01
Error(b)	112	5034.51		
Total	179			
CV (b):5.98				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respective

Appendix Table 7. Analysis of variance for Shoot dry weight of soybean genotypes

Source	DF	MS	F	P
Block	2	0.0207		
Amendment	3	92.20	3738.51**	0.01
Error(a)	6	0.068		
Genotypes	14	17.82	722.71**	0.01
Amendment*genotypes	42	1.872	75.92**	0.01
Error(b)	112	0.025		
Total	179			
CV(b) = 2.68				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 8. Analysis of variance for Root volume of soybean genotypes

Source	DF	MS	F	P
Block	2.0	0.1688		
Amendment	3.0	13.425	72.49**	0.01
Error(a)	6.0	0.0840		
Genotypes	14	3.8730	20.91**	0.01
Amendment*genotypes	42	0.4520	2.44**	0.01
Error(b)	112	0.1850		
Total	179			
CV(b)= 16.92				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 9. Analysis of variance for Root fresh weight of soybean genotypes

Source	DF	MS	F	P
Block	2	0.0914		
Amendment	3	14.172	226.65**	0.01
Error(a)	6	0.0762		
Genotypes	14	4.6805	74.86**	0.01
Amendment*genotypes	42	0.2975	4.76**	0.01
Error(b)	112	0.0625		
Total	179			
CV(b)= 8.43				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 10. Analysis of variance for Root dry weight of soybean genotypes

Source	DF	MS	F	P
Block	2	0.00136		
Amendments	3	1.25812	574.61**	0.01
Error(a)	6	0.00106		
Genotypes	14	0.30259	138.21**	0.01
Amendment*genotypes	42	0.03060	13.98**	0.01
Error(b)	112	0.00229		
Total	179			
CV(b) = 5.71				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 11. Analysis of variance for nodule fresh weight of soybean genotypes

Source	DF	MS	F	P
Block	2	0.0227		
Amendment	3	3.0596	242.04**	0.01
Error(a)	6	0.0092		
Genotypes	14	1.2592	99.61**	0.01
Amendment*genotypes	42	0.11176	8.84**	0.01
Error(b)	112	0.01264		
Total	179			
CV(b) : 9.27				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 12. Analysis of variance for nodule dry weight of soybean genotypes

Source	DF	MS	F	P
Block	2	0.00176		
Amendment	3	0.15022	259.75**	0.01
Error(a)	6	0.00127		
Genotypes	14	0.07211	124.64**	0.01
Amendment*genotypes	42	0.00362	6.25**	0.01
Error(b)	112	0.00058		
Total	179			
		CV(b): 9.03		

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 13. Analysis of variance for Shoot fresh weight of soybean genotypes

Source	DF	MS	F	p
Block	2	0.64		
Amendment	3	2080.71	6210.71**	0.01
Error(a)	6	0.38		
Genotypes	14	310.39	926.50**	0.01
Amendment*genotypes	42	44.75	133.60**	0.01
Error(b)	112	0.33		
Total	179			
CV(b): 2.33				

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.

Appendix Table 14. Analysis of variance for hundred seed weight of soybean genotypes

Source	DF	MS	F	P
Block	2	33.61		
Amendment	3	24.03	8.47**	0.01
Error (a)	6	3.86		
Genotypes	14	51.89	18.29**	0.01
Amendment*genotypes	42	2.88	1.02^{ns}	0.45
Error(b)	112	2.83		
Total	179			
CV(a) = 13.46		**CV(b) =11.54**		

Where; DF= degree of freedom; MS= mean square, ns,* and ** implies non significant, significant and highly significant differences, respectively.