INFULENCE OF POTASSIUM FERTILIZATION AND LIMING ON GROWTH, GRAIN YIELD, AND QUALITY OF SOYBEAN *(Glycine max* L. (Merrill) ON ACIDIC SOIL IN GOBU SAYO DISTRICT, WESTERN ETHIOPIA

MSc. THESIS

NEGASH TESHOME

OCTOBER, 2017
JIMMA, ETHIOPIA

INFULENCE OF POTASSIUM FERTILIZATION AND LIMING ON GROWTH, GRAIN YIELD, AND QUALITY OF SOYBEAN *(Glycine max* L. (Merrill) ON ACIDIC SOIL IN GOBU SAYO DISTRICT, WESTERN ETHIOPIA

A Thesis Submitted to the School of Graduate Studies of Jimma University College of Agriculture and Veterinary Medicine, Department of Horticulture and Plant Science in Partial Fulfillment of the Requirements for the Degree of Master of Science in Agronomy

NEGASH TESHOME

October, 2017

Jimma, Ethiopia

DEDICATION

This thesis is dedicated to my mother EJIGAYEHU AYANA for her nursing, really creating viaduct for the stage I attained and for her love.

STATEMENT OF THE AUTHOR

I undersigned and declare that this thesis is my veritable work and all sources of materials used as reference are duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at the Jimma University and is deposited at the University's Library to be made available for borrowers under the rules and regulations of the library.

Brief quotations from this thesis are allowable without special permission provided that appropriate acknowledgment of source is made. Requests for permission for extended quotation form or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the dean of the School of Graduate Studies. Under all other instances, however, permission must be obtained from the author.

Name: Negash Teshome Isho

Signature: ________________

Place: Jimma University

Date of Submission: __________________

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
ASP	Acid Saturation Percentage
BARC	Bako Agricultural Research Center
BNF	Biological nitrogen fixation
CSA	Central Statistical Agency
CSB	Corn-soy blend
EIAR	Ethiopian Institute of Agricultural Research
EM	Effective Microorganisms
ENI	Ethiopian Nutrition Institute
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agricultural organization statistics
GSWADO	Gobu Sayo Woreda Agricultural Development office
IFPRI	International Food Policy Research Institute.
LR	Lime requirement
LRF	Lime Requirement Factor
NFRDF	Nature Farming Research and Development foundation
OARI	Oromia Agricultural Research Institute
PAS	Permissible Acid Saturation
ppm	parts per million
USDA	United States Department of Agriculture
WHO	World Health Organization
WUE	Water use efficiency

BIOGRAPHICAL SKETCH

The author, Negash Teshome Isho, was born on 29 July 1984 in Bako Tibe Woreda, specifically at Gajo Kebele, in West Shoa Zone of the Oromia Regional State, Ethiopia. He attended his elementary education at Gajo Elementary School and his Junior Secondary education at Gudeya Jare and his high school was completed at Bako Senior Secondary School. He obtained his Diploma from Ambo College of Agriculture in general agriculture and has served at Bako agricultural research center as technical assistant for two years. He has got an opportunity to join Jimma University and obtained his BSc degree in Horticulture in 2011. After his graduation he returned to Oromia Agricultural Research Institute (OARI) and stationed at Bako Agricultural Research Center (BARC) and served in Horticulture Technology Generation Research Team as junior researcher in agronomy and conducted different agronomic research activities on horticultural crops for four years with various commitments and responsibilities in the institute until he joined the School of Graduate Studies in Jimma University for his MSc. study in Agronomy in October 2015.

ACKNOWLEDGEMENTS

First and foremost, it is my pleasure to express my heartfelt appreciation and special gratitude to my major research advisor, Dr. Weyessa Garedew for his unreserved support and encouragement which I enjoyed throughout the course of the study. His thorough review and constructive criticisms and suggestions on the thesis were among the most important factors that enabled me to shape up this thesis in its final form. In addition, I would like to express my heartfelt and special gratitude to my co-advisor Dr. Endalkachew W/Meskel for his profound and genuine guidance in all directions.

I would like to thank OARI in general specifically Bako Agricultural Research Centre especially Pulse and Oil Technology Generation Research Team for their contribution in seed supply and all professional supports. And my great heartfelt also for N2-Africa project in covering all research budget till its completion and BARC soil laboratory research team in analyzing the post-harvest experimental soils. I thank Jimma University, Post-harvest Management Department for helping in protein analysis, and Holeta Agricultural Research Center for their help in oil analysis.

Above all, I would like to give multitudes of praises and thanks to the supreme Almighty JESUS, who offered me everything. Without his sustained spiritual guidance and overall support, I would not have succeeded in every aspect of my life.

TABLE OF CONTENTS

TABLES **Page**

LIST OF TABLES

Tables **Page**

LIST OF FIGUERS

Figure **Page**

LIST OF TABLES IN APPENDIX

Appendix Table **Page**

ABSTRACT

The experiment was to evaluate the influence of potassium fertilization and liming on growth, grain yield, and quality of soybean (Glycine max L. (merrill) on acidic soil in Gobu Sayo district, western Ethiopia. Soil acidity problem is one of the bottlenecks to improve crop production in high rainfall areas of Ethiopia in general and in western parts of the country in particular. A field experiment was carried out during the 2016 main cropping season at three sites (Gishe, Laften and Ago). Five levels of potassium fertilizer (0, 20, 40, 60, and 80 kg ha^{-1}*) and two levels of lime (0 and 4.6 t* ha^{-1}*) were applied as two factors. Fifty (50) kg* ha^{-1} P_2O_5 *with seed inoculation by biological organism (legume fix strain) was also used as standard check. The eleven treatment combinations were arranged in a randomized complete block design (RCBD) with three replications. KCL was used as* K_2O *source and applied in two splits at planting time and at vegetative growth stage. The full dose of lime was broadcasted a month before planting on those plots which received lime. Soil samples were collected during pre-sowing and after harvesting to analyze for selected soil properties. The analysis of soil sample after harvest indicated that the soil pH was raised from very strongly acidic to slightly acidic level for Gishe and Laften sites and from strongly acidic to moderately acidic for Ago site. Furthermore, percent organic carbon and total nitrogen as well as exchangeable bases showed considerable increase after harvest for soil treated with lime at the rate of 4.6 t* ha^{-1}*. The analysis of variance indicated that there were highly significant interactions* ($P<0.001$) *between potassium and liming for all measured plant variables, except for number of primary branches, tap root length and number of seeds per pod. The highest soybean grain yield (*3642 *kg* ha^{-1}*) was obtained at Gishe site when 60 kg* ha^{-1} K_2O *and 4.6 ton* ha^{-1}*lime was applied while the lowest yield (1014 kg* ha^{-1}*) was recorded at Ago site for the control treatment. The partial budget analysis also revealed that application of 60 kg* ha^{-1} K_2O *with 4.6 t* $ha\text{-}^{1}$ *lime has a substantial economic advantage on acidic soils of the study areas. Application of* K_2O *significantly increased protein content of soybean seeds but lime and its interaction with* K_2O *or* K_2O *alone had negative effect in reducing oil content of soybean seeds. Hence,* K_2O *at a rate of 60 kg* ha^{-1} *with 4.6 t* ha^{-1} *lime can be recommended to increase production and productivity of soybean in acidic soils of the study areas. However, the response of soybean having different maturity groups and use of different biological strains should further be tested in combination with liming and potassium fertilizer to come up with conclusive recommendations.*

Key words: Acidic Soil, Growth, Grain Quality, Lime, Potassium, Soybean.

1. INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is a small erect and branching annual leguminous plant classified under the family *Fabacae* and sub family *Paplionodeae* (Sinclair *et al.,* 2001). Soybean grows from sea level up to 2200 meters above sea level, with in latitudes ranging from the equator up to 55º North and 55º South. It grows under a wide range of temperature, but the optimum temperature for its growth and development is 30 ºC, while for proper emergence of seedlings, a seedbed temperature of 25-33 ºC is said to be optimal. The crop requires 500-850 mm water during the growing season. It is the world's most grown oilseed. Of approximately 400 million Mt a year of oilseeds, 60% is from soybean. It also provides cholesterol free oil (20-22%) and best quality protein (42-45%). It contains essential amino acids, vitamins A, B, C and D and minerals such as Ca and P (Rahman, 1982).

Soybean is an important source of protein for small scale farmers who rarely obtain foods of animal products. It is a multipurpose crop and can be used for animal feed and raw material for industries as well as incorporates plant usable nitrogen in to soil through biological N fixation. In the future, soybean is assumed to be an important source for bio-fuels production. In most cases, soybean crops are processed for oil and meal, and soybean is the only plant food that contains complete protein that provides all essential amino acids required for human health. Soybean seed also contains carbohydrate, fatty acids, and minerals. Polyunsaturated fatty acids in diet have been shown to actively lower serum cholesterol levels (Hegstad, 2008). Soybean oil is rich in polyunsaturated fatty acids, including the two essential fatty acids, linoleic and linolenic, that are not produced in the body. Linoleic and linolenic acids help the absorption of vital nutrients required for human health, and soy products have also been shown to be useful in prevention and treatment of bone resumption, inhibiting ovarian, breast and colon cancer, and other chronic heart and kidney diseases (Chang *et al.* 2007).

In Ethiopia, grain legumes occupy about 13% of the cultivated land and their contribution to agricultural value addition is around 10% (CSA, 2012). Pulses are the third-largest export crops of Ethiopia after coffee and sesame, contributing USD 90 million to export earnings in 2007/08

(IFPRI, 2010). Among food legumes grown in Ethiopia, soybean is gaining more importance in recent years. Extensive works have been done to incorporate soybean as a food legume in people's diets, either directly in seed form or processed into value-added foods (soy nuts, soymilk, and soy pulp) or added as a blend in traditional foods. Recently, the trend of increment in area under the crop is mainly due to a rising demand from domestic processing industries. Large-scale production of the crop may, therefore, enhance the income of small-scale farmers. The country can also earn a substantial amount of foreign currency from the export of soybean grain owing to the strategic location of the country to the world consumers.

In Ethiopia, its productivity is far below the from world average, as the national average yield of the crop is less than 2 tons per hectare (CSA, 2015). This is mainly due to lack of appropriate production packages, low productivity of varieties, soil acidity problem, and lack of promotional activities suitable for different cropping systems and agro-ecologies (Urgessa, 2015). Soil acidity and decline in soil fertility are forms of soil degradation adversely affecting sustainable crop production in Ethiopia in general, and in western Ethiopia in particular (Abdenna, *et al.*, 2007). Achieving optimum soil pH is essential for field crop production, because it affects many soil properties and processes, including nutrient cycling, soil microbial activity, and soil structure. Soil acidity affects root development, leading to reduced nutrient and water uptake and deficiency in essential plant nutrients, such as K, Ca, and Mg (Abdenna, *et al.*, 2007).

Recent studies showed that depletion of major nutrients is very high in Ethiopia particularly in western parts of the country (Abdenna, *et al.*, 2007). Low soil P availability due to its high fixation in acidic soils is limiting crop production. A study also showed that soil acidity increased on cultivated lands in western part of Ethiopia because of the intensity of the high rainfall (Achalu *et al.*, 2012). Moreover, different reports indicated that most cultivated lands of the Ethiopian highlands in general and western parts in particular are prone to soil acidity due to removal of ample amount of nutrients by leaching, crop mining and runoff as compared with grazing and forest lands (IFPRI. 2010). It is now becoming a serious challenge to crop production in these parts of the country and an inventory was made in 2006 to determine the current status of soil acidity of Nitisols occurring in western and central Ethiopia. The results revealed that all samples were acidic though the degree varied from location to location (Abdenna, *et al.*, 2007). These authors indicated that soil acidity problem that occurred particularly in western zones of Oromia was very critical and deserved immediate intervention to amend the soils for crop production. Increasing soybean production can save foreign currency paid for this import if productivity of the crop is improved through liming and potassium application indeed. Potassium is one of the three major essential nutrient elements required by plants. Unlike nitrogen and phosphorus, potassium does not form bonds with carbon or oxygen, so it never becomes a part of protein and other organic compounds (Hoeft *et al.,* 2000). Although K is not a constituent of any plant structures or compounds, it is involved in nearly all processes needed to sustain the plant life. Potassium in cell sap is involved in enzyme activation, photosynthesis, transport of sugars, protein and starch synthesis. It is known to help crop to perform better under water stress through the regulation of the rate at which plant stomata open and close. It is also known for its role to provide lodging resistance and insect/disease resistance to plants. Since potassium is involved in many metabolic pathways that affect crop quality, it is often called as "the quality element". Plants absorb K in larger amounts than any nutrient except N. Potassium (K) as essential mineral nutrient and is required in relatively large amount to maintain growth and play a central role in improving crop yield and quality (Abel *et al*., 2002). In our country in general and in western Ethiopia in particular, limited information is available on the role of potassium fertilizer on growth, yield and quality aspects of soybean.

Accordingly, Bako Agricultural Research Center in collaboration with N2-Africa project has conducted different research activities on legume crops production in Gobu Sayo District of East Wellega Zone for the last three years. The result indicated that application of phosphorus (P_2O_5) and inoculants/biological nitrogen fixers) significantly improved yield and yield related traits of soybean by 19%. However, yield response of the crop to the inputs was inconsistent over years and across the selected Kebele of the district (N2-Africa, 2013), as more than 25% of the sites showed inconsistent yield to the applied inputs. It was suspected that there were substantial variations among the selected Kebels for soil pH, available P and K, which might result in such variation in yield of the crop over years. Therefore, with the view to generate information, this study was initiated to evaluate the effect of potassium fertilizer and liming on growth, yield and quality of soybean in Gobu Sayo district, western Ethiopia.

Objectives

1.1. General objective

- To determine the response of soybean to potassium fertilizer and liming on acidic soils of Gobu Sayo district.

1.2. Specific objective(s)

- To determine the optimum rate of potassium fertilizer application and liming for improved growth, yield and quality of soybean on acidic soils of Gobu Sayo district in West Ethiopia.

2. LITRATURE REVEW

2.1. Production and Importance of Soybean in Ethiopia

Soybeans were first grown in Ethiopia in 1950. The main soybean-producing areas are in the western part of the country in the Oromia and Benishangul Gumuz Regional State, and to a lesser extent the Amhara region South Nation Nationality and People (SNNP) regions. In these regions, the top-producing zones are Illubabor, Horogudru Wellega, East and West Wellega, Awassa, Bako, Ambo Jimma, Metekel, Assosa, Kemashi, Awi and West Gojjam. In 1970s, Ethiopia produced 6,000 tons of soybeans a year, making it one of the top four African soybean producing countries. In 1981 about 2,000 hectares of land were under production by the state farms development authority; however, this accounted only for 10% of the soybeans required by the Ethiopian Nutrition Institute (ENI).

In Ethiopia soybean can be grown up to 2200 m.a.s.l altitude and with annual rainfall as low as 500-700mm, but performs best between 1300 and 1800m altitude with annual rainfall of 900-1300mm, an average annual temperature between 20-25°C and a soil pH of 5.5 to 7 (Gurmu, 2007). The growing season ranges from 90 to over 150 days and three different soybean varieties have been distinguished (Gurmu,2010): Early maturing group with 90-120 days (Awassa-95, Williams, Crawford and Jallale), Medium maturing group with 121-150 days (Clarck-63K, Cocker-240, Davis, Cheri and AFGAT), and Late maturing group with >150 days (Belessa-95 and Ethiougozlavia). Other varieties such as Katta, Korme, Diddessa, Boshe etc. are also under production in Ethiopia (Gurmu, 2007). Soybean varieties such as Gazale, Pawe-01, and Pawe-02 were newly released by 2015. A seed rate of 60-80 kg ha^{-1} with a row spacing of 40 cm x 5 cm for early maturing varieties and 60 cm x 5 cm for medium maturing varieties were recommended for production. Potential crop yields are as high as 3.5 t/ha (Gurmu, 2010).

Including soybean in the crop rotation is an indigenous practice in Ethiopia that has agricultural and social benefit. Soybean offer the benefit of nitrogen sparing, they use less of the available nitrogen in the soil compared to a none-fixing plants, thereby “sparing” it for the succeeding crop. It may also supply a residual effect, where the biomass of the legume plant is returned to the soil and the nitrogen available in the plant will be released in an inorganic, plant-available form to the crop that follows the legume in rotation (Giller, 2001).

Products from soybean are exceedingly required for the populations in Ethiopia who are often affected by protein-energy malnutrition and for those who have constraints to include animal sources of foods in their diets. Moreover, soybeans are a source of high value animal feed. In Ethiopia, particularly in the capital city, Addis Ababa, Faffa Food Share Company, East African Flour Factory, and Health care food manufacturing private limited companies etc. are using local and imported soybeans in the preparation of enriched food products for children and adults (WHO, 2003). Recently the factory is trying to improve the food value of other food types by mixing soybean floor. In addition to oil, soybeans are used to make a variety of local foods, such as bread, chappati, porridge, soy milk, yoghurt as well as the traditional Ethiopian stew, shero wot. Soybeans are also used to make corn-soy blend (CSB) for emergency food assistance programs run by international organizations and the Ethiopian government. This indicates that the importance of soybean in the market is increasing gradually. There is also a large scarcity in high protein animal feed for the booming dairy, export beef and poultry sectors. Similarly, there is strong demand from the nutritious food industries; factories that supply to the World Food Program alone have a total annual demand of 60,000 tons to cater for soy blends for the food insecure and malnutrition affected areas (Urgessa, 2015).

2.2. The Concept of Soil Acidity

Soil acidity is now a serious threat to crop production in most highland area of Ethiopia in general and in southern and western parts in particular. Currently, it is estimated that about 40% of the total arable land of Ethiopia is affected by soil acidity (Abdenna *et al*., 2007; Taye, 2007). From these 27.7% moderately to weak acids with pH 5.8-6.7 and 13.2% covered by strong to moderate acidic soils with pH less than 5.5 (Schlede, 1989).

Soil acidity affects the growth the crop because acidic soil contain toxic levels of aluminum and manganese and characterized by deficiency of essential plant nutrients such as P, Ca, K, Mg, and Mo (Wang *et al.*, 2006). At pH below 5, aluminum is soluble in water and becomes the dominant ion in the soil solution. In acid soils, excess aluminum primarily injures the root apex and inhibits root elongation. The poor root growth leads to reduced water and nutrient uptake, and consequently crops grown on acid soils are confronted with poor nutrients and water availability. The net effect of which is reduced growth and yield of crops (Wang *et al*., 2006). Soil acidity is expanding both in scope and magnitude in Ethiopia even though it varies from location to location and severely limiting crop production (Abdenna *et al*., 2007). The strongly acid soils are found in ecologies which receive or have historically received high incidence of rainfall and have warm temperatures much of the year. They are often found in Oxisols, Nitosols, and Ferralsols. Thus, the most strongly acidic soils are found in western and south western parts of Ethiopia, the central highlands, the high rainfall areas of north western part of the country. Nevertheless, moderately acidic soils (pH 5.5- 6.5) are distributed through much of the rest of the country (Taye, 2008). In moving from central (West Shoa) to western Ethiopia (West wellega), the degree of soil acidification that is measured in terms of acid saturation percentage is increased (ASP>60). In western and eastern wollege zones, the large proportions exchangeable acidity was due to exchangeable Al while at west shoa zone it was due to Exchangeable H. The acidity problem in east and west wellega zone of oromia region is critical (Abdenna *et al.,* 2007) and deserved immediate intervention to amend the soils for crop production. As a case in point, a site specific study of soils around Asosa and Wellega revealed that in aggregate, some 67 percent had pH values less than 6 and were very strongly to strongly acidic (Mesfin, 2007). In some cereal crop growing areas (barley and wheat) of central and southern Ethiopia, farmers have shifted to producing oats which is more tolerant to soil acidity than wheat and barley (Desta, 1988). Considering this fact, the Federal Government of Ethiopia has identified soil acidity as a key agricultural problem and directed the concerned stakeholders to find integrated and sustainable solution to address the problem (Abdenna *et al*., 2007).

Lime application to acidic soils is one of the solutions to address soil acidity problem (Brady and Weil; 2002). There are voluminous research findings indicating that liming raises the pH of soil thereby making unavailable nutrients in to available form to crops. Cognizant of this fact, there was a massive campaign coordinated by Federal Ministry of Agriculture in 2006 to treat acidic soils with lime in Ethiopia aimed at increasing the productivity of acidic soils. Appreciable improvements in the yield of crops like barley and wheat was obtained. However, liming practice exercised during earlier periods was not based on research results relating to lime requirement of different soils and different crops. The extent of benefit that can be obtained with liming was also not well known. Based on this fact, liming experiments were conducted in different parts of our country for example southern Ethiopia (Chencha and Hagere Selam) on crops like potato, barley and wheat. The results revealed that application of lime alone did not improve the yield of crops tested. It was further found that liming with application of NP fertilizers improved the yield of crops to some extent. However, dramatic increases in the yield of all crops was obtained with lime plus NPK and when NP was applied along with K suggesting that K is a limiting nutrient at acidic soils of Chencha and Hagere Selam areas. Lime + NPK and NPK treatments increased the yield of potato at Chencha testing site from 7.9 t ha^{-1} in the control to 35 t ha^{-1} and 41 t ha^{-1}, respectively in 2007 (Wassie *et al*., 2009). It also shows that, if the soil gets depleted of nutrients, liming alone will have limited effect on crop growth (Potash Institute, 1979). The importance of K as a limiting nutrient was further substantiated by the results of parallel experiments conducted in 2007 and 2008 on potato at Chencha that there was a steady increase in the yield of potato to K application up to 150 kg ha^{-1} (Wassie and Shiferaw, 2011).

2.2.1. Soil pH range

The pH of a soil is a measure of hydrogen ion activity (H^+) in the soil solution. As the H^+ activity increases, soil pH decreases. As the soil pH decreases, most desirable crop nutrients become less available while others, often undesirable, become more available and can reach toxic levels (Ristow *et al*, 2010). Soil acidity is identified by the measurement of soil reaction (pH). The term pH stands for the potential (p) of the hydrogen ion (H^+) in water. pH is actually a way of reporting the amount of hydrogen ion in solution using an electrical "potential" expressed as the negative logarithm of hydrogen ion activity/concentration of a soil which means that for each unit increase in pH there is a 10 times change in acidity (so a soil with a pH of 5 is 10 times more acid than a soil with a pH of 6 and 100 times more acid than a soil with a pH of 7. On the basis of their relative degree of acidity, soils are divided into several acidity or alkalinity classes (Brady and Weil, 2002) as shown in Figure 1. Such a classification enables the uses of proper terms for indicating acid-base conditions in soils.

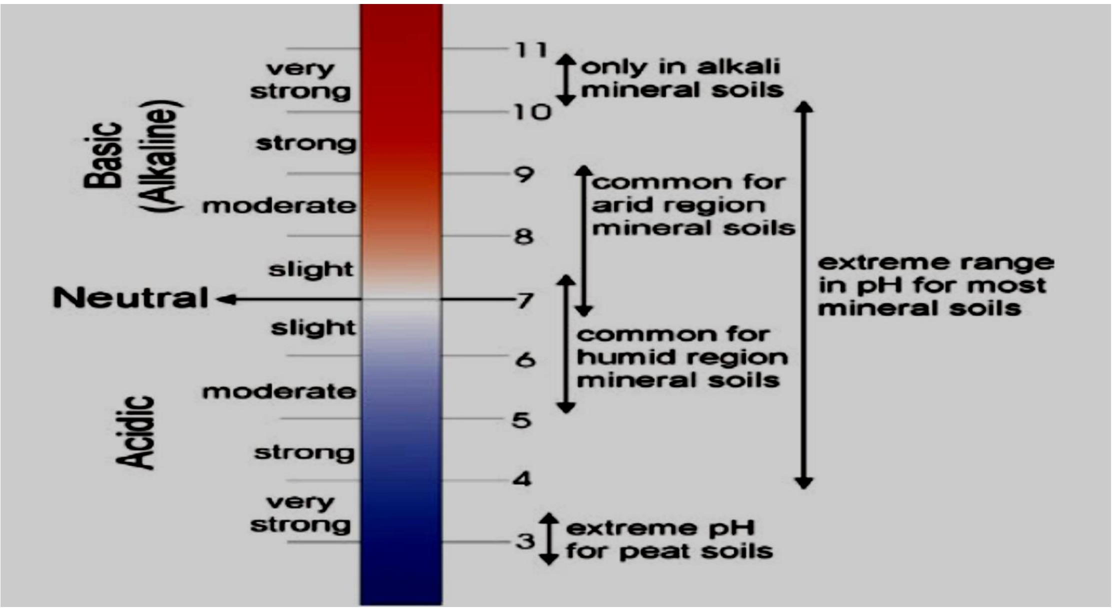


Figure 1. General soil pH ranges and reaction classes of soils (Source: Brady, 1980).

The ideal pH range for soil is from 6 to 6.5 because most plant nutrients are in most available state. If a soil pH test indicates a soil pH of below 6.5, the usual recommendation is for application of ground limestone. In addition to having the ability to raise soil pH, lime stone contains calcium. Some prefer dolomitic lime stone because it contains both calcium and magnesium, however soils high in magnesium (serpentine) do not need more magnesium. Acidic soils (pH<7) are common in humid regions. In these soils, the concentration of H^+ ions exceeds that of OH^- ions. Most plants grow best in soils with a slightly acidic reaction. In this pH ranges nearly all plant nutrients are available in optimal amounts. Soils with pH<6 will more likely be deficient of some of available nutrients for optimal plant growth. Calcium, magnesium, and potassium are especially deficient in acidic soils. In strongly and very strongly acidic soils, Al, Fe, Mn may exist in toxic quantities because of their increased solubility. In addition, these elements will react with phosphates (primary & secondary orthophosphates) to form insoluble phosphates on phosphate retention and fixation (Kim, 2010).

2.2.2. Causes of Soil Acidity Problems

Major reasons for soils to become acidic are: rainfall and leaching, acidic parent material, organic matter decay, harvest of high yielding crops, removal of products from the farm or paddock, inappropriate use of nitrogenous fertilizers.

The above causes of soil acidity are more easily understood when we consider that a soil is acidic when there is an abundance of acidic cations, like hydrogen (H^+) and aluminum (Al^{3+}) present compared to the alkaline cations like calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+) (Jackson, 1967).

Rainfall and leaching: Wet climates have a greater potential for acidic soils. In time, excessive rainfall leaches the soil profile's basic elements (calcium, magnesium, sodium, and potassium) that prevent soil acidity. In conditions where rainfall exceeds evapo-transpiration (leaching) during most of the year, the basic soil cations (Ca, Mg, K) are gradually depleted and replaced with cations held in colloidal soil reserves, leading to soil acidity. Soil acidity is really a high rainfall problem (Slattery and Hollier, 2002). Clay soils often contain Fe and hydroxyl Al, which affect the retention and availability of fertilizer cations and anions in acidic soils. Sandy soils are often the first to become acidic because water percolates rapidly, and sandy soils contain only a small reservoir of bases (buffer capacity) due to low clay and organic matter contents. Since the effect of rainfall on acid soil development is very slow, it may take hundreds of years for parent material to become acidic under high rain fall (Jackson, 1967).

Parent Material: Due to differences in chemical composition of parent materials, soils will become acidic after different lengths of time. Thus, soils that developed from granite material are likely to be more acidic than soils developed from calcareous shale or limestone (Jackson, 1967).

Organic matter decay /Dissociation: While organic matter has many beneficial effects including improving soil structure, the increasing amount of organic matter may make the soil more acid. Decaying organic matter produces H^+ which is responsible for acidity. The carbon dioxide (CO_2) produced by decaying organic matter reacts with water in the soil to form a weak acid called carbonic acid (Slatter and Hollier, 2002). This is the same acid that develops when CO_2 in the atmosphere reacts with rain to form acid rain naturally. Several organic acids are also produced by decaying organic matter, but they are also weak acids. Like rainfall, the contribution to acid soil development by decaying organic matter is generally very small, and it would only be the accumulated effects of many years that might ever be measured in a field (Slatter and Hollier, 2002).

Crop Production and nutrient removal: Harvest of high-yielding crops plays the most significant role in increasing soil acidity. During growth, crops absorb basic elements such as calcium, magnesium, and potassium to satisfy their nutritional requirements. The way that plants take up nutrients results in a partitioning of acidity into the soil and alkalinity into the plant as dry matter. If a plant was naturally allowed to die and all parts returned to the soil, there would be no net change in pH. As agriculture removes plant material from a paddock (as grain or pasture) less alkalinity is returned to the soil and the soil becomes more acidic. Different crop species have a range of ash alkalinity because they accumulate different amounts of nutrient cations. Thus, when various agricultural products are exported from the field, the corresponding effect on the acidification of the soil varies with the ash alkalinity of crops. The greater the ash alkalinity, the greater the acidifying effect on soil of export (Nelson *et al.,* 2007). Increasing crop yields will cause greater amounts of basic material to be removed. Grain contains less basic materials than leaves or stems. For this reason, soil acidity will develop faster under continuous wheat pasture than when grain only is harvested. High yielding forages, such as Bermuda grass or alfalfa, can cause soil acidity to develop faster than with other crops. Note that there is almost four times as much lime material removed in the forage as the grain. This explains why wheat pasture that is grazed out will become acidic much faster than when grain alone is produced. Using 50 percent ECCE lime, it would take about one ton every 10 years to maintain soil pH when straw (or forage) and grain are produced annually at the 30 bushel per acre level.

Use of nitrogenous fertilizers: The natural rate of acidification is accelerated by agricultural practices like use of nitrogen fertilizers. The use of NH4+ containing fertilizer over long period leads to soil acidification (Bolan *et al.,* 1991). However; the impact of nitrogen fertilizers on acidification depends on the type of fertilizer (Slattery and Hollier, 2002). The degree of acidity caused by a fertilizer is modified by soil characteristics, cropping systems, environmental variables. Fertilizers may also cause acidity by increasing the export of basic cations relative to the unfertilized soil (Bolan *et al*., 1991).

Table: 1. Acid generating ammonium nitrifying reactions in soil

Ammonium nitrate	$NH_4NO_3 + 2O_2 \rightarrow 2NO_3^- + 2H^+ + H_2O$
Urea	$(NH_2)_2CO + 4O_2 \rightarrow 2NO_3^- + H^+ + CO_2 + H_2O$
Anhydrous ammonia	$NH_3 + 2O_2 \rightarrow NH_3^- + H^+ + H_2O$
Ammonium phosphate	$NH_4H_2PO_4 + 2O_2 \rightarrow NO_3- + H_2PO_4- + H_2O + 2H^+$
Ammonium sulphate	$(NH4)_2SO4 + 4O_2 \rightarrow 2NO_3- + SO_{42}^- + 4H^+ + 2H_2O$

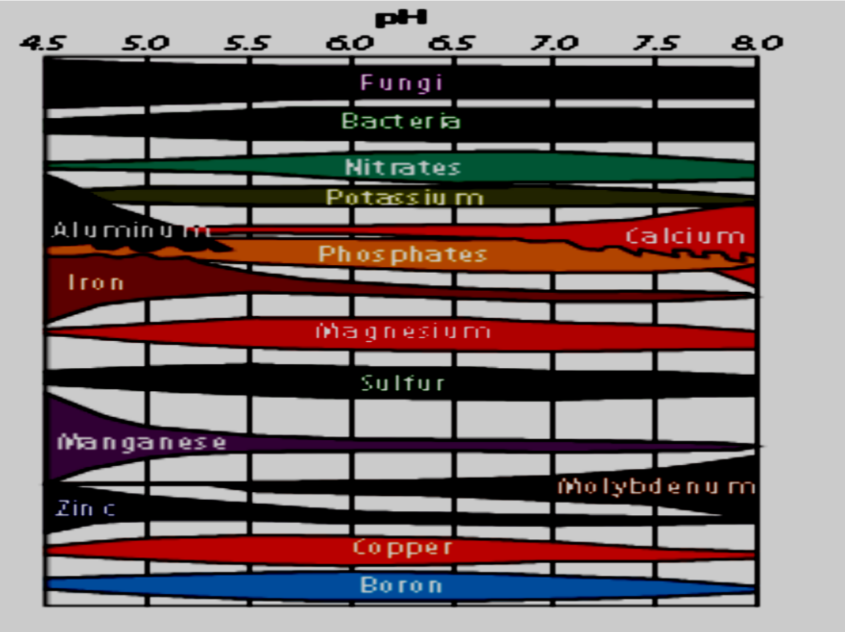
Source: Kennedy (1992).

Two processes are involved. First, commonly used nitrogen fertilizers contain ammonium nitrogen (urea is an ammonium forming material). Soil bacteria convert ammonium ($NH4^+$) to nitrate (NO_3^-) through a biochemical process called nitrification (Bolan *et al*., 1991). Hydrogen (H^+) is released in this process, and free hydrogen ions cause an increase in acidity. The second acidifying effect comes from nitrate that is not taken up by the growing crop. Nitrates are very soluble and, if not taken up by plants, will move downward with soil water and may be carried below the root zone. They take with them other nutrients that have a positive charge-most likely calcium and magnesium-and their removal in this manner has the same acidifying effect on soils as removal by a crop (Bolan *et al*., 1991).

2.3. Effect of Soil Acidity

The optimum soil pH for plant production is one that is slightly acidic, at this pH soil microorganisms are most active and plant nutrients are readily available. At extremes of high (alkaline) and low (acid) pH this delicate balance is disturbed and plant nutrients that were in adequate supply can become either deficient or toxic to plant growth (Slattery *et al.,* 2000).

. Some essential nutrients such as phosphorous, calcium, magnesium, and molybdenum become unavailable if the soil pH becomes too acid as shown in Fig. 2. Acid conditions will result in a lowering of plant production in farming systems. This will result in reduced profitability and an increased reliance on fertilizers to sustain any form of productive agriculture. Correcting soil pH to a more favorable pH range will increase the availability of essential nutrients (Slattery *et al.*, 2000).



Source: (Brady and Weil, 2002).

Figure 2.The availability of plant nutrients and toxic elements.

The width of the line indicates increasing or decreasing availability across a pH range from strongly acidic to strongly alkaline. Note how nitrogen, phosphorous, potassium and sulphur become much less available at low soil pH. Nutrient toxicity can occur in acid soils when the pH is 4.8 or lower (Slattery *et al.*, 1999). The two most important toxicities in acid soils are those of aluminum (Al) and manganese (Mn) (Slattery *et al.*, 1999). In strongly acid soils (pHW< 4.3) aluminum and manganese become more available in the soil solution and are harmful to plant roots. Aluminum toxicity is the most common plant symptom on acidic soils and causes root stunting (Slattery *et al.*, 2000). Reduced root growth impedes nutrient and water uptake and results in decreased production. Some plants are more tolerant than others to high levels of Al in the soil solution; however, as the pH declines so too do the farming options for utilizing plants that are aluminum tolerant. There is a danger in the development of more acid tolerant cereal and legume cultivars, since the use of these acid tolerant crops has the potential to further extend the use of the soil resource in the strongly acid pH range. If this happens, then soil degradation could reach a level, which is irreversible. The use of these practices will lead to a poorer soil resource that is expected to maintain current crop production and one that cannot be returned to its former state. Clearly, there is a need to conserve this valuable resource as much as possible and preventing soils from becoming strongly acid is one strategy. Important productive plants such as Lucerne, phalaris, canola and barley are difficult to establish and grow in acidic soils. Both low pH and toxic aluminum (Slattery *et al*., 1999) irreversibly affect the establishment of Lucerne. The growing of deep-rooted perennial pastures (such as Lucerne and phalaris) is seen as an answer to slowing the acidification process (Slattery *et al.*, 1999*)*. If these plant species cannot be established because soil pH is too low, then nitrate leaching will continue, thus increasing the rate of acidification and increasing the recharge of water into aquifers, leading to further dry land salinity problems. Slattery *et al.* (1998) has shown that soil clay loss from primary clay minerals is a severe consequence of allowing soils to remain at a pH of 4.0 or lower for an extended period (10 years). Over the time frame of one farming generation, little apparent harm is done to the soil's mineral framework by permitting acidification of weathered soils. However, it is clear that permitting unabated acidification over longer periods will cause the soil to continue losing clay and to increase its silica content.

2.4. Management option of soil acidity problems

It is now increasingly realized that integrated soil fertility management involving combination of microbial inoculants (bio-fertilizer), inorganic and organic fertilizer are essential to sustain productivity of acidic soils and maintain soil health for long run (Bejiga, 2004; Ellafi *et al.,* 2011). This is especially important for developing countries, like Ethiopia where farming will continue to be in the hands of small scale farmers. The agronomic and management options to correct acid soils integrated nutrient management (inclusive of lime, organic manure and inorganic fertilizers, appropriate crop rotations and crop mixtures, and use of plant species and varieties tolerant to Al and Mn toxicity) to increase the crop productivity. The synergistic effects of lime, NPK and farmyard manure (FYM) application on maize yield in an acid Alfisol (pH 4.6) of Meghalayawere (Sanchez and Salinas, 1981).

Soil pH is an important soil property, because it affects the chemical, biological, and physical processes of the soil. Thus, pH is often considered the “master variable” of soil. Soil acidity has long been known to induce P and N deficiency in legumes Al and Mn toxicity as well as Ca and P deficiency in the soil inhibit Rhizobium growth and root infection resulting in symbiotic failure (Negi *et al.*, 2006). Lime application neutralizes soil acidity, reduces toxicity levels of Al, Fe and Mn and improves physiological, chemical and biological properties of soils (Kisinyo *et al*., 2005). It also improves soil productivity by providing Ca and Mg. It is found that as the lime and P application to acidic soil increased plant available Fe, Mn, Zn and Cu, but B contents of soil decreased, whereas pH, Ca, Mg and available P increased which in turn improve crop performance. The extension of this approach in semiarid region of Ethiopia appears to be promising. So, for economically feasible and sustainable agricultural production in acidic soils liming is required. Application of lime to acidic soil supply Ca^{+2}, Mg^{+2}, which is essential to plant growth and neutralize toxicity effect of H^{+}, Al^{+3}, Mn^{+2}, in the soil. On the other hand it raises pH of the soil at which atmospheric N fixing inoculants/ *Bradyrhizobium* acts best and phosphorus reach its optimum availability at soil pH(6.5) (Negi *et al.* 2006). Because at lower pH (strongly acidic) available forms of P(Secondary Orthophosphate ($HPO4^{-2}$)**)**, Primary Orthophosphate (H_2PO4^{-}), sorbed P and others are fixed to the positive charges of (Al^{+3}, Fe^{+}, Mn^{+2}, H^{+}) & unavailable to them impairment of nodulation and N2 fixation by legume Rhizobium symbiosis is noticed when legumes are grown on acidic soils. There for, N deficiency resulting in growth and yield reduction. In this regard, Rice *et al.* (2000) reported that soil pH had significant effect on plant growth and development which directly faces on growth and yield of the crop. It is now increasingly realized that integrated soil fertility management involving combination of microbial inoculants(bio-fertilizers), inorganic and organic fertilizers are essential to sustain productivity of acidic soils and maintain soil health for long run (Bejiga, 2004; Ellafi *et al*., 2011). This is especially important for developing countries, like Ethiopia where farming will continue to be in the hands of small scale farmers and soil acidity accounts 41% of the arable land.

Lime application

Lime requirement refers to the amount of lime required to neutralize all or part of the acidity in soil (both solution and reserve) from an initial level to a desired or target less acid condition. Liming of acid soils starts from the basic assumption that neutral soils are base-saturated while acid soils that contain exchangeable hydrogen and aluminum are base-unsaturated. Each soil has a region of buffering. In other words, soils behave like buffered weak acid and resist sharp changes in reaction (pH) with the addition of bases. That is why two or more acid soils could have identical pH values but vary in total acidities. For instance, an acid soil rich in organic matter could have similar pH values with a soil poor in organic matter. As a result, the amount of base or lime required to neutralize it to a desired level of total acidity could be diametrically different than the soil poor in organic matter. In other words, the percentage base saturation or the proportion of the cation exchange sites balanced by basic cations would be different. Conversely, if such soil is progressively neutralized with bases, the quantity of base needed to reach pH 7 is considered to be a measure of the total acidity of that soil or its lime requirement (Juo and Manu, 1996).Traditional methods of managing acidic soils for agriculture in the humid tropics, such as slash-and-burn agriculture practiced in its various forms, also rely on the "application" of carbonates in this case in the form of ashes produced by the burning of woody and vegetative materials. Ash contains a large proportion of the carbonates of mineral cations (K, Ca, & Mg) originally present in the vegetation (Friesen *et al*., 1980).

The target level of soil acidity depends both on the soil and the crop. The crop affects the lime requirement (LR) through its level of tolerance to acid soil conditions. The type of soil affects the LR through its contents of reserve acidity which maintains a given concentration of toxic H^+ and Al^{3+} in soil solution. Neutralization of soil acidity involves not only neutralization of H ions in soil solution but also all or part of the soil's reserve acidity. The process of neutralization is essentially a three-step reaction most of which occurs in soil solution or between the soil solution and the cation exchange surface. Liming of acidic soils to a pH of 5.5 or 6.0 neutralize exchangeable Al^{3+} and Mn^{2+} toxicity, while supplying Ca and (dolomite lime) magnesium. This generally improves phosphorous uptake by plants. By reducing Al toxicity in acidic soils, liming often increase the effective crop rooting depth, allowing a bigger soil volume to be explored for nutrients and water by the crop. Liming also improves the availability of some but not all micro-nutrients. Various liming materials are available for correcting soil acidity. The neutralizing value relative to calcium carbonate depends on their composition and purity. A material with a relative neutralizing value of less than 100% requires a heavier application than $CaCO_3$ to neutralize an equivalent amount of soil acidity. The neutralizing value of a liming material may be determined in the laboratory by reacting the material with a known amount of acid. Since the material is generally insoluble in water, it is usually dissolved in an excess of acid and the excess is determined by tit ration with standard base solution. Actual (as opposed to estimated or calculated) lime requirement may be affected by the re-activity of the liming material. Less reactive materials may require heavier application rates to compensate. Since neutralization of acidity involves the reaction of H^+ ions in solutions with the surface of lime particles, particle size can affect the rate of reaction. More finely grounded particles react more rapidly with soil acidity since they have a greater total surface area than coarsely ground limestone. Organic matter application and using acid tolerant/resistant crop varieties are also important in managing and made acidic soil to be more productive.

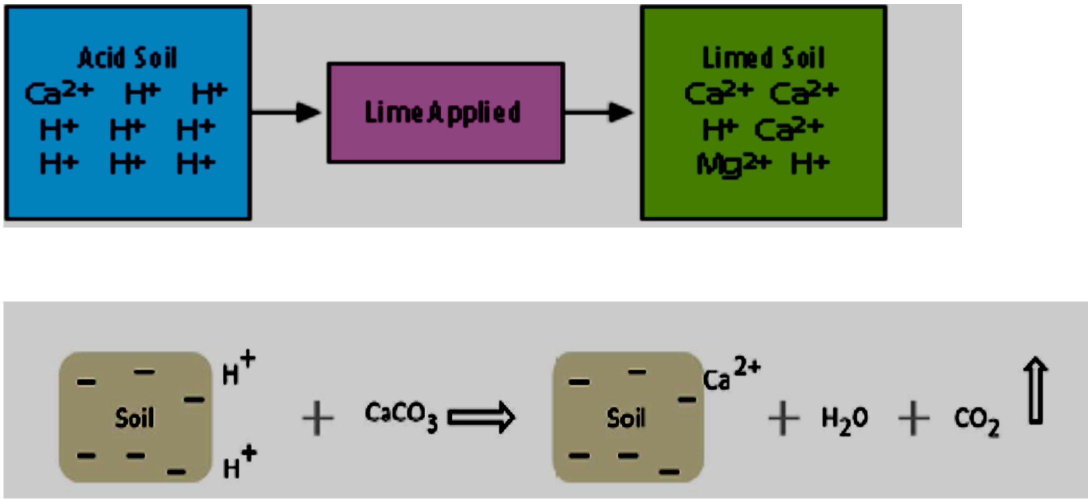


Figure 3. Importance of liming acid soils in increases exchangeable Ca and Mg.

The chemical reactions that take place in soil when lime is applied are shown in Figure 4. The lime dissolves to form calcium, bicarbonate, and hydroxide ions. The hydroxide neutralizes soil acidity by combining with hydrogen ions to form water. As the concentration of hydrogen ions decreases, the pH increases. Addition of lime can counterbalance the acidity of a soil. This is a two-step process that involved replacement of H^+ and Al^{3+} ions on the clay surfaces (Figure 4) with Ca from the liming material followed by neutralization of the acidity by reaction of the H^+ and Al^{3+}ions with $CaCO_3$ to form aluminum hydroxide, water and carbon dioxide (i.e. Acidic soil Al^{3+}/H^+ + $CaCO_3$ (calcium carbonate) and Exchange each other neutral soil(Ca^{2+}, Mg^{2+})+H,$^+$ Al^3+ HCO_3^{2-} implies neutralization $(Al\ OH)_3 + CO_2 + H_2O$) is a neutral Compound)

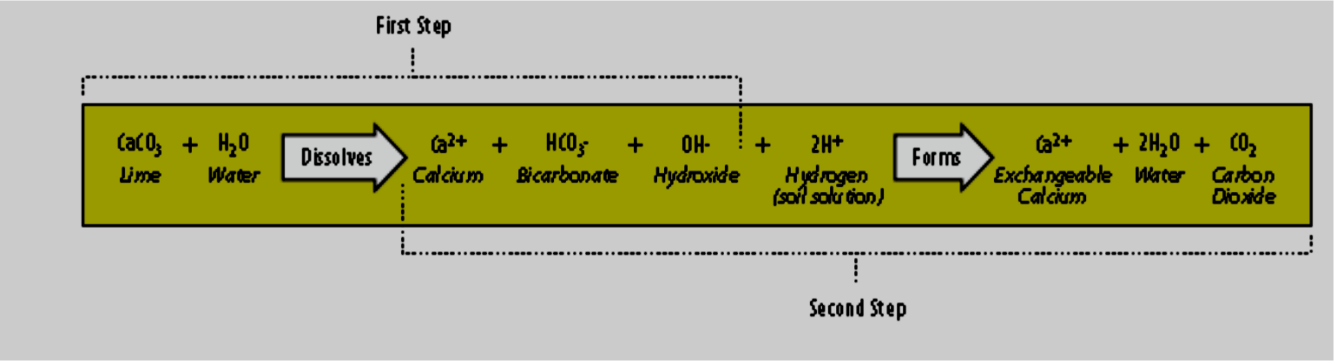


Figure 4. The chemical reaction that occurs when agricultural lime is added to an acidic soil.

Estimation of lime rate

Soils tests help determine the amount of lime required to raise soils to a desired pH. Perform a lime requirement test on all soils with a pH of 5.1 or lower. Soil pH is more critical for legumes such as alfalfa, lentils, Soybean and peas than for cereals. Consequently, for soils testing less than pH 5.5 performs a lime requirement test where legumes are grown. Numbers obtained from lime requirement soil tests are often meaningless when soil pH values exceed 5.6. Several different lime requirement tests have been developed to determine the amount of lime needed for improving crop yields. A lime requirement test is necessary for determining the correct amount of lime to apply because over-applications may decrease soil productivity. In addition to soil pH, soil texture, clay content, cation exchange capacity (CEC), base saturation, and other factors affect the amount of lime needed.

The level of soil acidity that is tolerable in any situation is determined by the permissible acid saturation (PAS) of the crop to be grown. If soil acid saturation exceeds the PAS, the excess acidity has to be neutralized by liming. If it is assumed that the neutralizing value of the lime available is 75% that of pure CaCO3 (this will be dependent on purity and hardness, and in particular in fineness of the product) and that incorporation depth is 15 cm, the lime needed per hectare to eliminate an exchangeable acidity of 1 meq/100g will be approximately 3000 kg. If the neutralizing value of the lime is lower or higher than 75% the lime requirement factor will be adjusted accordingly (Taye, 2008). Accordingly, lime requirement is calculated using acid saturation as follows LR = LRF (EA –PAS). Where, LRF = Lime Requirement Factor, PAS=Permissible Acid Saturation, EA= Exchangeable Acidity

2.5. Potassium Status in Ethiopian Soils

Soil type and environmental conditions have an effect on the amount of potassium available for plant use. Potassium availability is highest under warm, moist conditions in soils that are well aerated with a neutral or slightly acidic pH (Brady and Weil, 2002). There has been a long established understanding, that Ethiopian soils are rich in potassium and so there is no need for the application of fertilizers containing K (Murphy, 1968). According to Fassil (2008) in the history of Ethiopian Agriculture the role of potash fertilizer in crop production is ignored for many years. A study conducted by the author reveals that only 20% of the soils have sufficient exchangeable K, whereas 80% of the soils are deficient in exchangeable K. The assessment done in six Vertisols locations of Tigray region by Fassil and Charles (2009) revealed that 76% of the investigated soils were deficient in potassium. The findings of Abegaz (2008) who studied the K content of three soil types from the Atsbi-Wemberta district of Tigray, northern Ethiopia, also showed that K was deficient in a Luvisols under barley production.

2.5.1. Potassium in Plant Physiology

The nutrient absorption by plants depends on the growth, efficiency of roots and the availability of nutrients in the soil (Silva *et al*., 2002). Potassium is an essential nutrient for plant growth. Because large amounts are absorbed from the root zone in the production of most agronomic crops, it is classified as a macro-nutrient. Soils can supply some K for crop production, but when the supply from the soil is not adequate, thus K must be supplied in a fertilizer program (George and Michael, 2002). The exact function of K in plant growth has not been clearly defined. Potassium is associated with movement of water, nutrients, and carbohydrates in plant tissue (Gardia *et al*., 1980). If K is deficient or not supplied in adequate amounts, growth is stunted and yields are reduced. Potassium uptake by plants is affected by several factors. Such as soil moisture, soil aeration and oxygen level, soil temperature and tillage system (George and Michael, 2002).

2.5.2. Importance of Potassium (K) on yield and quality of soybean

Potassium is an essential nutrient needed for plant growth. Soils can provide much of the K that is needed by plants, but when supply becomes limiting, there is a need for supplemental K fertilization. Research on the effects of K fertilization for corn and soybean were studied extensively in the past. Potassium dissolves from fertilizer in the soil, is attracted to clay particles, and is then held tightly enough that leaching losses are negligible. In sandy soils which have very little clay, leaching losses of potassium can be a problem. The fixation of potassium (K) and entrapment at specific sites between clay layers tends to be lower under acid conditions. This situation is thought to be due to the presence of soluble aluminum that occupies the binding sites. One would think that raising the pH through liming would increase fixation and reduce K availability; however, this is not the case, at least in the short term. Liming increases K availability, likely through the displacement of exchangeable K by Ca. The availability of the micro-nutrients manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and boron (B) tend to decrease as soil pH increases. Young seedlings of soybean do not use much potassium, but the rate of uptake climbs to a peak during the period of rapid vegetative growth. The potassium in vegetative parts is transferred to seed during pod fill process. The mature soybean seed contains nearly 60% of the total K in plant (Hoeft *et al.*, 2000). It is to be noted that on weight basis, soybean seed contains more than twice as much as potassium in corn grain.

Potash is a general term used to describe a variety of K containing fertilizers used in agriculture. It is always present in minerals as a single-charged cation (K^+) (Baque *et al.*, 2006). Soybean crop takes up and removes large amounts of potassium from soil than any other nutrient (Tiwari *et al*, 2001). Potassium application have shown to increase the number of pods as well as exerted a beneficial influence on retaining pods until harvest in soybean (Coale, F.J. and Grove, J.H. (1990). Potassium fertilization can be either applied to soil or as foliar spray to plants. Soil application is the standard form of application and has its own advantages unless soil pH and other factors affect the movement and uptake from soil to the plants. Foliar application can rapidly help plants to recover from stress due to drought, high heat, pests and diseases. The conventional way (Nelson *et al*, 2007 and Fernandez, 2012) to apply K to the soil is before planting (pre-planting), and larger quantity may improve soil fertility for subsequent crops. Previous research has focused on foliar fertilization of soybeans at late reproductive stages and produced inconsistent and insignificant results. However, foliar application is still attracting researchers' interest (Hiller, 1995) to evaluate effective rates and timing of application to avoid drought and heat stress at critical stages. Studies have shown that both pre-plant and foliar K applications can increase soybean yields with low to medium soil K levels. Although foliar and soil application of K fertilizers have been used to maintain optimum level of nutrients in crop, there is limited information on the effect of foliar and soil K fertilizer on seed composition (protein, oil, fatty acids, and minerals).

On loamy sand soil, split application of potassium was found beneficial than applying full dose at the time of planting. Soybean responded significantly up to 50 kg K_2O ha^{-1} when applied 50% at planting and 50% at flower initiation (two splits) or 1/3 at planting, 1/3 at flower initiation and 1/3 at pod development (three splits). The per cent agronomic efficiency, percent physiological efficiency and per cent apparent K recovery reduced as the rate of applied K was increased from 50 to 75 kg K_2O ha^{-1}. On sandy clay loam soil, Annadurai *et al.* (1994) observed that the application of 40 kg K_2O increased the soybean seed yield and oil content.

2.5.3. Source of potassium and management practices

There are many unrefined and manufactured sources of potassium, but plants always absorb potassium in the form of K^+. The most commonly used potassium sources are potassium chloride (60% K_2O), potassium sulfate (50% K_2O), potassium magnesium sulfate (22% K_2O), potassium nitrate (44% K_2O), and animal manures (1-2% K_2O) (Mengel and Kirkby, 2001;Kinekar, 2010). Placement of potassium fertilizers with or near the seed is usually the most effective and efficient methods of application fertilizer. The annual applications should be based on the results of routine soil tests for K. Any potash needed for crop production can be applied in a band near the seed at planting or broadcast and incorporated before planting.

When applied in a band, the recommended broadcast rate of potash can be reduced by one-half without causing a reduction in yield (George and Michael, 2002).Soil type and environmental conditions have an effect on the amount of potassium available for plant use. Potassium availability is highest under warm, moist conditions in soils that are well aerated with a neutral or slightly acidic pH (Juff, 2014). According to Hasan (2002), too much water in the soil profile will lower oxygen levels, which in turn decreases plant respiration reducing potassium uptake. In clay soils, potassium availability can be affected due to its competition with calcium and magnesium for sites on the cation exchange. Both calcium and magnesium can easily displace potassium from the cation exchange. Thus, soil type and CEC determine the amount of potassium that is available for plant uptake. It is difficult to build soil potassium levels especially in soils with a high percentage of clay. Clay provides hiding places for potassium to bind and become unavailable for plant uptake (Juff, 2014).

2.5.4. Potassium Deficiency Symptoms

Potassium dissolves from fertilizer in the soil, is attracted to clay particles, and is then held tightly enough that leaching losses are negligible. One would think that raising the pH through liming would increase fixation and reduce K availability; however, this is not the case, at least in the short term. Liming increases K availability, likely through the displacement of exchangeable K by Ca. Like phosphorus, potassium is a primary nutrient used in large quantities by plants. K deficiency in crops does not immediately result in visible symptoms because of the high rate of redistribution between mature and developing tissues. At first there is only a reduction in growth rate (hidden hunger) and only later do chlorosis and necrosis begin in the more mature leaves (Gardia, 1980., Mengel and Kirkby, 2001). As Rengel and Damon (2008) reported, potassium is mobile in plants and will move from lower to upper leaves in most plant species, the older leaves show chlorotic and necrotic symptoms as small stripes along the leaf margins, beginning at the tips and enlarging along leaf margins in the basal direction. This deficiency has an impact on numerous synthetic processes, such as synthesis of sugar and starch, lipids and on the formation of leaf cuticles, cuticles protect plants against water loss and infection by fungi. In many cases, K-deficient plants tend to be more susceptible to infection than those with an adequate supply of K (Holzmueller *et* *al*., 2007). Williams and Smith (2001) also reported that increased K fertilizer significantly reduced the disease incidence of stem rot and aggregate sheath spot.

2.6. Benefits of using rhizobia inoculants

Nitrogen is an essence to life both for plants and animals. In spite of its abundance in the atmosphere, nitrogen (N2) is inert and cannot chemically be combined with other elements into usable forms by plants. On the other hand, because of environmental concerns and economic constraints, nitrogen requirement of crops cannot often be met solely through mineral fertilization. For the same reason, the use of leguminous crops for this inert nitrogen fixation and incorporation into agricultural soil is getting prime importance in Ethiopian context (W/Meskel, 2007; Bekere and Hailemariam, 2012; Bekere *et al*., 2013). Rhizobia inoculants are selected strains of beneficial soil microorganisms cultured in a laboratory and packed in with or without a carrier. They are host-specific, low cost and an environmentally friendly source of nitrogen. Rhizobia inoculants coated on legume seeds before planting enhance growth and yield of legume crops and provide nitrogen and organic carbon for subsequent or associated crops. Incorporating legume crop residues will make this effect even more significant. The coated seeds must be planted in moist soil as soon as possible. Phosphate fertilizers help the rhizobia inoculants work well with the legume. Rhizobia inoculants can improve and sustain soil fertility and soil health when used as part of a long-term rotation system. Nodulation generally starts 3 to 4 weeks after its emergency and inoculation is the least expensive way to provide nitrogen to soybean plants. These inoculants help provide nitrogen but other nutrients should be added to crops in line with the recommendations.

2.7. Importance of phosphorus in legumes growth

Phosphorus (P) is among 17 essential nutrients for plant growth. Its functions cannot be performed by any other nutrient, and an adequate supply of P is required for optimum growth and reproduction (Uchida, 2000). Phosphorus is classified as a major nutrient, meaning that it is required by crops in relatively large amounts. Despite the considerable amount of total P in tropical soils, P deficiency is one of the most important fertility problems in tropical agriculture. The importance of P in biological nitrogen fixation (BNF) is well known, as it is an energy driven process (Haru and Ethiopia, 2012). Phosphorus is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next (Uchida,2000). Generally, P is vital to plant growth and is found in every living plant cell. Phosphorus is the second most critical plant nutrient over all, but for legumes it assumes primary importance (Sinclair and Vadez, 2002). Plants need phosphorus for growth throughout their life cycle, especially during the early stages of growth and development. The primary role of phosphorus compounds in plants is to store and transfer energy produced by photosynthesis to be used for growth and reproduction (Leidi and Rodriguez-Navarro, 2000). On the other hand, Lambers *et al*., (2006) pointed out that, phosphorus is required in large quantities in young cells particularly shoots tips where metabolism is high and cell division is rapid. Sufficient phosphorus is also required to enhance plant growth, promote nodulation, early maturity and grain formation in legumes (Kamara *et al*., 2010).

Study by (Shahid *et al.*, (2009) indicated that increased phosphorus application significantly enhanced plant height. Apart from growth, Gangasuresh *et al*., (2010) noted that phosphorus is a crucial element in legume crop production which plays an important role for many characteristics such as sugar and starch utilization, photosynthesis, cell division and organization and nodule formation. Phosphorus is an essential element for growth, development and yield of soybean. Soybean demand for P is greatest during pod and seed formation (Shahid *et al.*, 2009). A lack of this element is doubly serious since it may prevent other nutrients from being absorbed by soybean plants (Barkert and Sfredo, 1994). Phosphorus deficiency is wide spread in many agricultural regions and it causes substantial economic losses (Sinclair and Vadez, 2002). Even though soil phosphorus is quite abundant but it reacts readily with iron, aluminum and calcium to form insoluble compounds at both moderate to extreme soil reaction. These reactions results in very low phosphorus availability and low efficiency of phosphorus fertilizer used by plants (Jodie and Pete, 2000). Therefore, insufficient levels of phosphorus may hinder plant growth; lower the chlorophyll accumulation which limits photosynthesis in turn decrease in shoot growth, affects the photosynthetic activity, and limits the transport of photosynthates to nodules (Lambers *et al.*, 2006). Commonly, inadequate phosphorus slows the processes of carbohydrate utilization, development of a dark green leaf color or plants leaves developing a purple color (Samavat *et al*., 2012). Furthermore, low levels of P and N found in most tropical soils, together with in adequate compatible rhizobial strain to a particular legume plants may result in poor plant growth, ineffective nodulation and lower yield in general. Therefore, extra application of phosphorus fertilizers to soil improves the root growth, and then enhancing the shoot growth subsequently increases the yield component of the crop development where more than 60% of P ends up in the pods and seeds (Samia *et al*., 2012).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

A field experiment was conducted during the 2016 main cropping season under rain-fed condition on three purposively selected farmer fields in Ago Laften Kebele of Gobu Sayo district, Western Ethiopia. Ago Laften is one of the nine Kebeles found in Gobu Sayo district in East Wollega Zone of Western Oromia. Gobu Sayo district is located about 265km to the west of Addis Ababa. The district is characterized by altitudes ranging from 1200 to 1960 meters above sea level. Its total annual rainfall is as high as 2000 mm and has average temperature ranging from 15 -20 ^{0}c. The district has mono-modal rainfall pattern with alternative wet and dry seasons with the main rain falling between April and November, while being dry throughout the rest of the months (Personal contact). The selected sites for the experiment were assumed to be representative of the whole sampled areas of the location, where yield inconsistencies were recorded in previous studies. The soil of the district is nitosols with low fertility range because of high rainfall and dominance of mono-cropping system by cereal crops.

Table: 2. Description of Experimental Location/Site

Locations/Sites	Altitude (m.a.s.l)	Latitude	Longitude
GISHE	1900	9^0 13' N	36^0 09' E
LAFTEN	1960	9^0 15' N	36^0 09' E
AGO	1865	9^0 11' N	36^0 09' E

Source: GPS data recorded in 2016/17

The sites were selected based on the results of pre-sowing soil analysis done for ten farmers' fields where yield inconsistences were observed in previous studies (N2-Africa 2013). The soils of the selected farmers' fields are texturally clay with pH of 4.9, 4.91, and 5.18 for Gishe, Laften and Ago respectively. These values indicate that the soil is very strongly acidic for the first two locations and strongly acidic for the third location, respectively. Besides, it was suspected from the soil analysis result that there is an indicator that shows deficiency of exchangeable bases, especially (potassium) in these areas.

The district is approximately located between $9^{o}0’30’’$N to $9^{o}20’30’’$N latitude and $36^{o}53’30’’$E to $37^{o}7’00’’$E.longtude

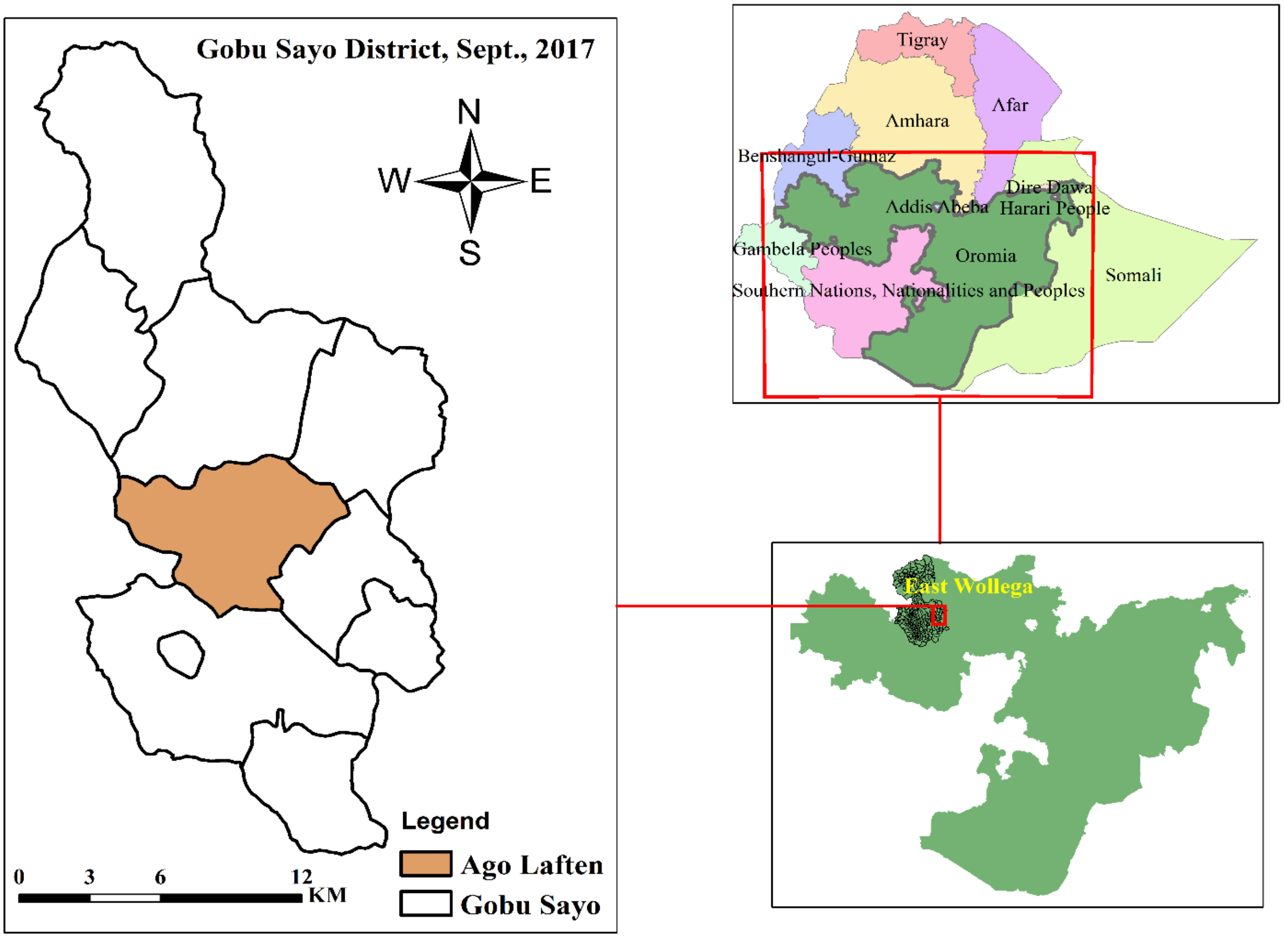


Figure 5. Graphical representation of the study area

3.2. Treatments and Design

Five rates potassium (K_2O) (0, 20, 40, 60, and 80 kg ha^{-1}) combined with two levels of lime ($CaCO_3$) (0 and 4.6 t ha^{-1}) were used as treatments. Moreover, the recommended rate of phosphorous for in the study area (50 kg ha^{-1} P_2O_5) with bio-fertilizer inoculation (legume fix bio-fertilizer) was used as a standard check which is recommended by BARC before (Table 2). The bio-fertilizer was brought from Holeta Agricultural Research center. The treatment combinations were arranged in Randomized Complete Block Design (RCBD) with three replications. Soybean variety, Jalalle (AGS-217), which is an early maturity type (90-120 days), was used for the experiment. The variety was released by Bako Agricultural Research Center in 2003. A seed rate of 80 kg ha^{-1} were used for the experiment. This variety gives an average yield of 1.5 t ha^{-1} and 2.2 t ha^{-1}on farmers and research fields respectively (BARC). Soybean was planted on gross plot size of 3.6 m x 2.4 m having nine rows; the net plot size of the experiment was 2.4 m x 2.4 m having six harvestable rows by leaving two border rows and one distractive row. A spacing of 40 cm x 5 cm were used between rows and plants, while 1m by 0.5 m was left between blocks and plots, respectively. Gross experimental plot was 12.8 m x 31.4 m at each for location.

Table: 3. Treatments and their combinations

TRT. Code	Treatment Combinations	
T1	0 t ha^{-1} lime + 0 kg ha^{-1} K_2O	(negative Control)
T2	0 t ha^{-1} lime + 20 kg ha^{-1} K_2O	
T3	0 t ha^{-1} lime + 40 kg ha^{-1} K2O	
T4	0 t ha^{-1} lime + 60 kg ha^{-1} K2O	
T5	0 t ha^{-1} lime + 80 kg ha^{-1} K_2O	
T6	4.6 t ha^{-1} lime + 0 kg ha^{-1} K_2O	
T7	4.6 t ha^{-1} lime + 20 kg ha^{-1} K_2O	
T8	4.6 t ha^{-1} lime + 40 kg ha^{-1} K2O	
T9	4.6 t ha^{-1} lime + 60 kg ha^{-1} K_2O	
T10	4.6 t ha^{-1} lime + 80 kg ha $^{-1}$ K_2O	
T11	50 kg ha^{-1} P_2O_5 + inoculation with	legume fix strain (Standard check)

3.3. Experimental Procedure

Land preparation was done at the beginning of May, 2016 by using local plough (*maresha*) according to farmers' conventional practice using oxen. Field layouts and fine seed bed was prepared according to the design. Lime was applied to plots which receive the treatment one month before of planting to buffer the soil and each treatment was assigned randomly to the experimental units within a block. Planting was done at the end of June, 2016. Potassium (K) was applied in two splits applications at time of planting and at rapid vegetative growth stage when plants transit from vegetative to flowering stage, because young seedlings of soybean do not use much potassium, but the rate of uptake climbs to a peak during the period of rapid vegetative growth. Manual weed control and all recommended agronomic practices for the crop were performed during the cropping season, and no chemicals was applied to control pests and insects.

3.4. Data Collected

3.4.1. Soil physico-chemical properties

An initial soil sample was taken using Auger at a depth of 0-30 cm from10 farmer fields. It was collected from five randomly selected spots diagonally across the experimental field before sowing and composited and analyzed at JEJE Analytical Service Soil Laboratory. The samples were analyzed for organic carbon, total N, soil pH, available phosphorus, cation exchange capacity (CEC), exchangeable bases (Ca, K, Na, Mg), some micro nutrients (Cu, Fe, Mn, and Zn) and for textural class. The particle size distribution (soil texture) was done by Bouyoucos hydrometric method. Finally the post-harvest soil samples were collected from an individual plot of the three locations, air dried, ground by mortar and pistil and passed through a 2 mm mesh sieve for physico-chemical analysis and the samples from each replication were mixed for a treatment and got ready for analysis. The analysis was done at Bako Agricultural Research Center (BARC) soil laboratory based on the standard procedure of soil analysis methodology and analyzed for Ava. Phosphorous, pH, Organic matter, Organic carbon, Total nitrogen, cation exchange capacity (CEC), exchangeable basic cations (Ca, Mg, and K). Organic matter was determined based on the oxidation of organic carbon with acid dichromate medium following the Walkley and Black method. Kjeldahl method was used to determine total nitrogen. Soil Cation Exchange Capacity (CEC) was determined as well. Available soil phosphorous was determined according to the methods of Olsen and Dean (1965). The soil pH was determined in 1:2.5 (weight/ volume) soils: water dilution ratio using a glass electrode attached to a digital pH meter**.**

3.4.2. Phenological and growth parameters

Stand count: The number of plants in the net plot area seedlings was counted after establishment and at harvest and converted to hectare basis.

Days to 50 % emergence: Days to 50 % emergence was recorded as number of days from date of sowing to the time when 50 % of the seedlings emerged in each plot.

Days to 50 % flower initiation: Days to 50 % flower initiation was recorded as the number of days from sowing to the time when at least one open flower appeared on 50% of the plants in a plot at any node on the main stem.

Plant height (cm): Plant height was recorded for five randomly selected plants from harvestable rows in each plot at physiological maturity and it was measured from the base (ground surface) to the tip of main stem of the plant.

Number of primary branches per plant: It was determined by counting the average number of primary branches on the main stem of five randomly selected plants in each plot at physiological maturity.

Root length (cm): Tap root lengths were measured for randomly selected five plants from distractive row and the average value was determined.

Nodule volume (ml): Nodules collected from roots of each plant were put in a graduated cylinder half filled with water and the volume of the displaced water was measured to estimate nodule volume.

Root Volume (ml): After the roots were thoroughly washed and soils removed, the whole root mass containing nodules, was put in a graduated cylinder with already measured volume of water and the root volume was estimated as compared to the volume of the displaced water.

Total nodule number/plant: All nodules collected from randomly selected five plants in distractive rows were counted and the average number per plant was calculated.

Effective nodules per plant: The number of effective nodules out of the total number of nodules per plant at 50% flowering was determined by dissecting each nodule and observing the cross section of the nodules, where nodules which showed a strong pink to dark red color were considered as effective while those showing green, brown, or white color were considered as ineffective nodules. The strong pink color of the nodule while slicing/dissecting is caused by the presence of leghemoglobin, which is indicator of active nitrogen fixation capacity of the nodules.

Nodule fresh weight (gm): Fresh weight of nodules collected from five randomly plants selected per plot was recorded using sensitive balance and the mean value was taken as nodule fresh weight per plant.

Nodule Dry Weight (gm): After determining fresh weight, the nodules were oven dried at 70-80 ^{o} c to a constant weight and their dry weight was recorded using a sensitive balance.

Shoot biomass yield at its vegetative growth stages/mid flowering (gm): Its fresh and dry weight status of biomass yield at mid flowering for five plants randomly selected /plot from distractive row was taken to evaluate the dry matter accumulation of the plant at this stage. Above ground shoot biomass dry weight was collected at maximum vegetative growth stages/mid flowering is important to estimate the dry matter accumulation of soybean at this growth stage. Its weight was taken for randomly five plants selected from distractive row and dried with a temperature of 70-80 ^{o}c until it attain constant within an oven dry and the data were recorded.

Days to physiological maturity: Days to 90% physiological maturity was recorded as the number of days from date of sowing to the date when 90% of the plants showed yellowing of leaves and pods and seed hardening in the pods.

3.4.3. Yield and Yield Components

Above ground dry biomass (gm): The total above ground dry biomass of five randomly selected and tagged plants per net plot area was determined by harvesting close to the soil surface at physiological maturity and by sun-drying to a constant weight. Finally the biomass yield plants selected was converted to hectare and expressed in kg ha^{-1}.

Number of seeds per pod: Randomly selected five plants were taken from harvestable rows, and the total number of seeds were threshed and counted to determine the average number of seeds per pod.

Pod length (cm): Randomly selected five plants was taken per plot and their pod length was measured for five pods per plant and the mean value recorded.

Number of pods per plant: The total number of pods on five randomly selected plants from each net plot area was counted at the time of harvest and the average value was expressed as the number of pods per plant.

Hundred seed weight (gm): Hundred seeds were counted from the harvested bulk of seeds per net plot and their weight (g) was determined at 12.5% moisture content by using a sensitive balance. Hundred seed weight is also an important yield component which reflects the magnitude of seed development that ultimately affects the final yield of a crop.

Grain/seed yield (kg ha^{-1}): Grain yield was measured after allowing the harvested plants to dry in an open air until they attained constant weight. Finally the yield from net plot area of each treatment was converted to hectare basis and the average yield was expressed in kg ha^{-1}.

Harvest index: The harvest index was calculated as the ratio of grain yield to total above ground dry biomass yield i.e. it is a ratio between economic character (seed yield) and total plant dry weight (seed yield + straw weight). It is very useful in measuring nutrient partitioning in crop plants, which provides an indication of how efficiently the plant utilized acquired nutrients for grain production.

3.4.4. Grain Quality

Oil and Protein contents: Protein and oil contents of soybean seed were evaluated for each observations at any one representative location (Gishe). Oil quality was analyzed at Holleta Agricultural Research Center Laboratory and crude protein content was analyzed at Jimma University College of Agriculture and Veterinary Medicine, in post-harvest department laboratory.

Determination of crude protein procedure

Crude proteins content of seed samples was determined using micro-Kjeldahl method of nitrogen analysis as described by AOAC, 2005, method 988.05. Accordingly, about 0.3 gm of sample was measured by analytical balance (Model: ABJ220-4M, Australia), 1 gm of catalyst mixture of K_2SO_4 and $CuSO_4$ and 5 mL of sulfuric acid was added to each digestion flask (Kjeldahl flask KF250,German) which contained sample and catalysts. The solution (0.3 gm of sample + 1 gm of K_2SO_4 and copper sulfate + 5 mL of H_2SO_4) in the dejection flask was immediately placed at about 420^oC for 4 hrs, until it became clear. The digested sample was then transferred into the distillation apparatus and 25 mL of 40 % (w/v) Na OH was continually added to the digested sample until the solution turned cloudy, which indicated that it become alkaline.

The mixtures were then steam distilled and the liberated ammonia was collected into a 200 mL conical flask containing 25 mL of 4 % boric acid plus mixed methyl red indicator solution. Next distillation was carried out into the boric acid solution in the receiver flask with the delivery tube below the acid level. As the distillation was going on, the pink color solution of the receiver flask turned green, indicating the presence of ammonia. Distillation was continued until the content of the flask reaching the required amount. The green color solution was then titrated against 0.1N HCl solutions. At the end point, the green color turned to red pink color, which indicated that, all the nitrogen trapped as ammonium borate has been removed as ammonium chloride. The distillate was titrated with standardized 0.1N sulfuric acid to a reddish color. Ultimately the percentage of nitrogen content was estimated using the following formula *Eq (5)*.

Total nitrogen percent by weight (%N) = $\frac{(VA-VB)*N*14.007}{W} * 100$

Where

V_A = *volume (mL) of the HCl solution consumed in the sample titration*
V_B = *volume (mL) of the standard solution used in the sample blank titration*

N = *Normality of hydrochloric used which was 0.1N*
W = *weight of sample (g)*

The crude protein content was estimated using the formula *Eq (6)* =

Crude protein content (percent per weight) $= 6.25 * \text{total nitrogen}$

3.4.5. Statistical Data Analysis

All the collected data were subjected to analysis of variance using SAS version 9.3 and Gene Stat 18th edition. The results of soil analysis were subjected to descriptive statistics and pre-sowing values were compared with post-harvest results. Duncan's multiple range test at 5% level of significance was used to separate the treatment means that showed significant differences. Before the data was subjected to analysis of variance (ANOVA), homogeneity and normality test was done for all locations. Pearson's correlation analysis was done for some growth, yield and yield related parameters of soybean. Pooled mean yield for the three locations was used to compare both the new combination of factors with the standard check.

Partial budget analysis was done for the factors combined (K_2O and lime) to check either they are economically sound or not by the following formula: It was analyzed by estimating the price for both potassium and lime per hectare bases. A quintal of potassium was estimated 1000 Birr (source: ATA, personal contact). For lime, only labor and transport cost was considered.

$$\text{MRR (\%)} = \frac{\text{Change of net return/benefit}}{\text{Change of total variable cost}} \text{ X } 100$$

Where: MRR = is marginal rate of return.

4. RESULTS AND DISCUSSIONS

4.1. Soil Physical and Chemical properties

4.1.1. Pre-sowing Soil Samples

Results of pre-sowing soil analysis showed that soils of the experimental sites were clay in texture with a pH of 4.9, 4.93, and 5.18 for Gishe, Laften and Ago sites respectively (Table 4). These values can be rated as very strongly acidic for the first two locations and strongly acidic for the third location. It implies that essential plant nutrients are fixed in soil colloidal particles and because unavailable to plant growth. Soil analysis results showed that available P was found in the low range that means phosphate sorption/fixation occurred in soil colloidal particles and the nutrient was unavailable to plant growth because phosphates are negative charged and are attracted to or bound up with strongly to positively charged minerals, such as toxicity of Al^{+3}, Mn^{+2}, Fe^{+}, H^{+}. Consequently acidic soil causes deficiencies of exchangeable bases (Ca, Mg, and K) because the majority of the pre-sowing soil results indicated that those basic cations were found within low to medium range. Furthermore, the finer textured soils (clay) generally can sorb more phosphates because they have more surface area. Total nitrogen and organic carbon are also within low to medium range, indicating that all the experimental sites were deficient in most essential plant nutrients. Soils with pH<6 will more likely be deficient of some of available nutrients for optimal plant growth. Calcium, magnesium, and potassium are specially deficient in acidic soils. In strongly and very strongly acidic soils, Al, Fe, Mn may exist in toxic quantities because of their increased solubility. In addition, these elements will react with phosphates (primary & secondary orthophosphates) to form insoluble phosphates on phosphate retention and fixation (Kim, 2010).

Table 4. Pre-sowing physical and chemical properties of soils of the experimental site

	Rating	**Description**	**Rating**	**Description**	**Ratings**	**Description**	**References**
Location	**GISHE**		**LAFTEN**		**AGO**		
Soil Parameter							
Depth(cm)	0-30		0-30		0-30		
Textural class	Clay		Clay		Clay		JEJE Ser. Laboratory
pH(1:2.5 H2O)	4.90	Very strongly acidic	4.93	Very strongly acidic	5.18	strongly acidic	Rayment (1982)
TN (%)	0.22	Moderate	0.23	Moderate	0.11	Low	Bruce and Rayment (1982)
Av.P (ppm)	10	low	14	moderate	8	low	Bray pH< 7.4 (Olsen test P (ppm)
OC (%)	2.67	moderate	2.56	moderate	2.47	moderate	Tekalign 1991.
EC(dS/m)	0.11	-	0.08	-	0.07	-	
Exchangeable bases (cmol(+)/kg soil)							
Ex.Na	0.29	low	0.33	moderate	0.26	low	Source: Abbott (1989).
Ex.K	0.61	moderate	0.15	low	0.60	moderate	Source: Metson (1961)
Ex. Ca	9.67	moderate	8.21	moderate	9.53	moderate	Source: Abbott (1989).
Ex. Mg	3.22	moderate	4.93	moderate	3.18	moderate	Source: MAFF (1967),
CEC	23.82	moderate	22.00	moderate	20.82	moderate	Source: Metson (1961)

Where: pH (power of hydrogen), Av. p (available Phosphorous), OC (organic carbon), EC (electric conductivity), TN (total nitrogen), Na (sodium), K (potassium), Ca (calcium), Mg (magnesium), CEC (cation exchange capacity)

4.1.2. Post-harvest soil samples

The analysis of soil samples after harvest showed an increased level of P availability, soil pH, and basic cations as compared to pre-sowing results (Table 5 and 6). The soil pH values for the three locations increased/changed from very strongly acidic to slightly acidic (4.9 to 6.26) and (4.93 to 6.12) for Gishe and Laften, respectively) and from strongly acidic to moderately acidic (5.18 to 5.8) for Ago site. This result showed that application of lime at the rate of 4.6 t ha^{-1}caused an increase in soil pH at the three locations. This change in soil pH caused the fixed phosphates to available forms and also increased the availability of exchangeable basic cations (Ca, Mg, and K), percent total nitrogen, cation exchange capacity, and percent organic carbon in the soil. As a result, at Gishe 80% and at Laften 35.71% of available P was changed from moderate to high range, while at Ago site 87.5% of the available P was changed from low to moderate level. In line with this result, Prasad (1992) has reported that available soil P increased significantly under liming due to lowering P of fixation by other elements (Al, Mn, and Fe). Sood and Bhardwaj (1992) and Rahman *et al* (2001) have also reported that available soil P was higher under limed over the none-limed plots. The higher content of soil Ca, Mg, and K after harvest might be due to the direct addition of those elements from the liming material and/or greater availability of those elements at higher soil pH due to liming. In line with this, Prased (1992) and Samanta *et al*, (1994) have reported that exchangeable Ca in the soil increased significantly with higher dose of liming. Hillard *et al. (*1992) have also reported that lime increased soil pH and Ca and Mg contents in the soil. Furthermore, it has reported that lime application neutralizes soil acidity, reduces toxicity levels of Al, Fe and Mn and improves physiological, chemical and biological properties of soil (Kisinyo *et al.*, 2005).

Table 5. Post-harvest soil chemical properties for Ava. Phosphorus (Av.P), soil pH, % organic carbon (OC), % total nitrogen (TN), and Cation Exchange Capacity (CEC) of the experimental sites in 2016 main cropping season.

LOCATION	**GISHE**		
	Pre-sowing soil analysis results	Post-harvest soil analysis	
Parameters			Descriptions
Av.P (ppm)	10	18	from moderate to high
pH	4.9	6.26	from very strongly acidic to slightly acidic
% OC	2.67	3.82	-
% TN	0.22	0.33	from moderate to high
CEC	22.83	28.40	from moderate to high
LOCATION	**LAFTEN**		
Av.P (ppm)	14	19	from moderate to high
pH	4.93	6.12	from very strongly acidic to slightly acidic
%OC	2.56	3.39	-
%TN	0.23	0.29	from moderate to high
CEC	22	28.4	from moderate to high
LOCATION	**AGO**		
Av.P (ppm)	8	15	from low to medium/moderate
pH	5.18	5.8	from strongly acidic soil to moderately acidic
%OC	2.47	2.67	-
%TN	0.11	0.23	from low to medium
CEC	20.82	29.4	from moderate to high

Table 6. Post-harvest soil properties (exchangeable Bases (Ca, Mg, K (cmol (+)/kg soil)) as influenced by application of lime and potassium fertilizer ratesin 2016 cropping season.

	Pre-sowing soil analysis results	Post-harvest soil analysis	
LOCATION	GISHE		Descriptions
Ca	9.67	14.8	from moderate to high
Mg	3.22	25.8	from high to very high
K	0.61	1.48	from moderate to high
Na	0.29	-	-
	LAFTEN		
Ca	8.21	22.2	from moderate to high
Mg	4.93	20.5	from high to very high
K	0.15	1.43	from low to high
Na	0.33	-	-
	AGO		
Ca	9.53	17.2	from moderate to high
Mg	3.18	33.5	from high to very high
K	0.6	1.06	from moderate to high
Na	0.26	-	-

Where: Ca (calcium), Mg (magnesium), K (Potassium), and Na (sodium).

NB: The row data for post- harvest soil results in Appendix Table 1, 2, and 3) on page 82, & 83, which should have been summarized and presented under this sub-heading.

4.2. Phenological and growth parameters

4.2.1. Days to 50 % flowering

The number of days required for 50 % flowering was significantly (P=0.001) influenced by the interaction of lime and potassium over locations (Appendix Table 4).The longest (77.33) number time taken to flower was observed for application of 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime at Laften site (Tabe 7). This result was statistically non-significant with all K_2O rates both limed and unlimed conditions, except for Zero K_2O with zero lime and 80 K_2O with 4.6 t ha^{-1} lime. The shortest number of days taken to flower was observed at Ago site for all rates of lime and potassium (Table 7). Prolonged period for flowering could be due to an increase nutrient availability, as the availability of nutrients is more and more to plants there is high probability of that crop to stay in vegetative phase with extended flowering period. But even though the contribution of the interaction of these factors was great, the variation was most probably due to the effect of location (altitude). Soybean flowering/maturity was delayed with decreasing temperature mainly due to extended vegetative growth at Laften site as compared to the other sites. Because the majority of treatment combinations in this site was delayed to flowering and maturity. That means as altitude increases temperature decreases so plants in general and soybean in particular has the probability to stay vegetative than completing its life cycle.

4.2.2. Days to physiological maturity

Analysis of variance showed that days to maturity was significantly (P=0.001) affected by the three way interaction (Appendix Table 4). Soybean maturity was delayed by 13.22 % as a result of interaction of potassium and lime application over locations as compared to the control treatments. The longest maturity time (137days) was recorded for 80 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime application at Laften site and this result was statistically insignificant with the treatment combinations of 80 kg ha^{-1} K_2O with 0 lime, 20 kg K_2O with 4.6 t ha^{-1} lime, and 20 kg K_2O with 0 lime of the same site. While the shortest maturity period (121days) was recorded for all treatment combinations at Ago site (Table 7). Therefore, delay in maturity time of soybean was observed at higher rates of K_2O and lime interactions at Laften site. This might be due to the fact that liming enhanced availability of nutrients by neutralization of toxic elements in the soil (Al^{+3}, Mn^{+2}, H^+), and the positive effect of potassium on plant growth. In addition, like that of flowering, location effect was also great in delaying maturity of soybean at this site, since the crop is early maturity type (90-120 days).

Table 7. Mean days to 50% flowering (ADF) and maturity days of soybean as influenced by interaction of potassium and lime rates over three sites in Gobu Sayo district in 2016 cropping season.

				ADF			
	Locations	GISHE		LAFTEN		AGO	
Potassium levels kg ha-1	Lime rates (t ha-1)	0	4.6	0	4.6	0	4.6
0		73.67^{cdef}	70.67^{fg}	71.00^{efg}	76.67^{abc}	60.00^{k}	61.00^{k}
20		67.33^{hij}	65.67^{j}	74.00^{bcde}	76.33^{abc}	62.00^{k}	61.00^{k}
40		68.67^{ghi}	66.00^{ij}	74.33^{abcd}	77.00^{ab}	62.00^{k}	61.00^{k}
60		69.00^{gh}	70.67^{fg}	76.67^{abc}	77.33^{a}	62.00^{k}	61.00^{k}
80		72.33^{def}	70.67^{fg}	77.33^{a}	71.67^{defg}	61.00^{k}	60.00^{k}
CV (%)		2.5					
LSD (5%)		2.76					
				ADM			
0		126.33^{e}	125.00^{efg}	134.00^{b}	135.00^{b}	121.00^{kl}	121.00^{kl}
20		123.67^{gh}	126.67^{e}	135.33^{ab}	135.67^{ab}	121.6l^{kl}	121.00^{kl}
40		123.00^{ghijk}	126.33^{e}	134.33^{b}	131.00^{c}	121.67^{hkl}	121.67^{hkl}
60		128.67^{d}	124.00^{fg}	134.33^{b}	130.67^{c}	121.00^{L}	123.67^{ghijk}
80		125.67^{ef}	123.67^{ghi}	135.67^{ab}	137.00^{a}	121.00^{kl}	121.00^{kl}
CV (%)		0.9					
LSD (5%)		1.79					

Means followed by the same letter(s) within column and rows for a given variable are not significantly different at 5% level of significance.

4.2.3. Plant height (cm)

From the analysis of variance all the interactions and main effects showed highly significant differences (P=0.001) for plant height at physiological maturity stage over locations (Appendix Table 8). The highest value for plant height (100.13cm) was observed at Gishe site with the applications of 60 kg ha^{-1} K_2O and 4.6 t ha^{-1} lime, but it was statistically similar with 20 kg ha^{-1} K_2O without lime, 80 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime, 40 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime, and 80 kg ha^{-1} K_2O without lime. The lowest value (55.72 cm) was recorded for the control, which was statistically non-significant with the interaction of 60 kg ha^{-1} K_2O with 0 lime, 20 kg ha^{-1} K_2O with 0 lime at Ago site (Table 8).This result indicated that the interaction between lime and potassium has more contribution to the increase in soybean plant height. So, the variation in plant height might be because liming the soil has the capacity to release unavailable phosphates, and increases exchangeable bases that can be available to the plant which directly increased above ground biomass in general, and plant height in particular. The other possible reasons could be K application improves the growth and development of the crop, as it increases the nutrient uptake efficiency of plants and further improves the growth of other parts. The result is in line with Kumar and Chandra (2008) and Shahid *et al*. (2009), who have also observed significant improvement in plant height of soybean by P-fertilization. Furthermore, Oluwatoyinbo *et al*. (2005) have reported that plant height significantly increased by the application of lime. This may be attributed to the toxic effect of soil acidity, which may lead to stunting of plants under unlimed soils. The present findings are in agreement with the results obtained by Adel *et al.* (1994) who reported increase in plant height of soybean at high than at low rate of K application.

4.2.4. Total nodule number per plant

The number of nodules per plant was significantly (P=0.001) affected due to interaction of potassium fertilizer and lime rates over locations (Appendix Table 5). The highest number of nodules per plant (69.7) was obtained from interaction of 80 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime application which was statistically similar with the interaction of 40 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime applications at Gishe site. This could be due to the fact that liming the soil with potassium application can create suitable environment for nodulation parameters as a consequence of reduced soil acidity and increased soil pH. In line with this, Yoseph and Worku (2014) have reported that application of P resulted in a significant increase in nodule number. Whereas, the lowest number of nodules per plant was observed for the control treatment (0.00) at Laften and with all interactions at this site where nodulation was failed to occur as well non-significant for the control treatment of Ago (Table 8). If plants gets readily available nitrogen, there is no incentive to signal to rhizobia to form nodules and, thus, the rhizobia do not create nod factor. Once this carryover nitrogen is used up, the plant may signal to the rhizobia but the whole nodulation process then becomes delayed or the signaling window can be blocked, resulting in little to no nodulation on the soybean plants. As carryover nitrogen levels in the soil rise above 40 lbs /acre, nodule formation are negatively affected (Staton, 2014). In addition, if soil pH drops below 6, the conditions can become too acidic for rhizobia to effectively create nod factor that could affect rhizobia survival (Pedersen, 2015). Another reason could be unavailability/deficiency of important micronutrients including molybdenum used as cofactors for nitrogen fixation. Leguminous crops have not been grown at Laften site for the last 4 to 5 years, which probably resulted in absence of indigenous rhizobia that can be important as starter for nodulation. Without this organism, starting nodulation by using elite bacteria might be difficult for the first season of soybean production to form nodules. These and other causes are suspected for the absence of nodulation at Laften site.

Table 8**.** Mean plant height (PH) (cm) and nodule number (NNPP) of soybean as influenced by interaction of potassium and lime rates at Gobu Sayo district in 2016 main cropping season.

			PH(cm)				
	Location	**GISHE**		**LAFTEN**		**AGO**	
K2O(kg ha1)	Liming (t ha-1)	0	4.6	0	4.6	0	4.6
0		77.10^{fg}	88.30^{cde}	74.20^{gh}	81.60^{ef}	55.72^{L}	73.00^{gh}
20		98.93^{ab}	91.00^{cd}	81.87^{ef}	86.67^{cde}	58.33^{kL}	68.20^{hij}
40		85.93^{de}	93.33^{abcd}	89.93^{cd}	91.00^{cd}	86.15^{de}	64.00^{jk}
60		92.80^{bcd}	100.13^{a}	73.93^{ghi}	88.43^{cde}	62.00^{jkL}	66.67^{ij}
80		93.23^{abcd}	94.13^{abc}	76.83^{fg}	91.93^{bcd}	63.20^{jk}	87.40^{cde}
CV (%)		4.8					
LSD (%)		6.33					
			NNPP				
0		3.95^{jk}	45.30^{e}	0.0^{L}	0.87^{L}	0.57^{kL}	16.10^{h}
20		60.13^{c}	64.17^{b}	0.0^{L}	0.00^{L}	7.07^{ij}	18.93^{h}
40		27.33^{g}	68.10^{a}	0.0^{L}	0.00^{L}	7.20^{ij}	15.60^{h}
60		55.72^{d}	52.93^{d}	0.2^{L}	0.00^{L}	6.60^{ij}	25.00^{g}
80		41.20^{f}	69.70^{a}	0.0^{L}	0.00^{L}	8.80^{i}	24.00^{g}
CV (%)		9.8					
LSD (5%)		3.32					

Means followed by the same letters within columns and rows for a variable are not significantly different at 5% level of significance.

(A). LAFTEN SITE (no nodules at all) (B). GISHE SITE (with nodules) (C). AGO SITE (with nodules)

Figure 6. Photo taken during root and nodule measurements at Laften, Ago, and Gishe site.

Figure 7**.** Photo taken during collection data for nodulation parameters (Laften site).

4.2.5. Number of effective nodules per plant

Analysis of variance revealed that number of effective nodules per plant was significantly (P= 0.001) affected by the interaction of potassium fertilizer and lime rates over locations (Appendix Table 5). The highest number of effective nodules per plant (69.70) was recorded for the interactions of 80 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime rates at Gishe site and it was statistically non-significant with 40 kg ha^{-1} K_2O along with 4.6 t ha^{-1} lime applications at the same site. Whereas, the controlled control plots and all treatment combinations produced the lowest number of non-effective nodules effective nodules at Laften site (Table 9). This result indicates that all nodules especially at Gishe and Ago sites were effective in nitrogen fixation from the atmosphere and made available to the crop. This result is in line with the report of Adjei and Chambesiss (2002) and Bulter and Evers (2004) who reported legume nodules having dark pink or red centers denoting the presence of leghaemoglobin that is used as an indicator for effectiveness of the nodules and has positive coloration with N2 fixation.

Figure 8. Photo taken during visual evaluation of nodules for effectiveness at BARC laboratory.

4.2.6. Nodule volume per plant (ml)

The analysis of variance showed that the interaction of potassium and lime rates has highly significant effect (P= 0.001) on nodule volume per plant (Appendix Table 6). The highest nodule volume (5.95 ml) was recorded for the interaction of 80 kg ha^{-1} K_2O and 4.6 t ha^{-1} lime at Gishe. But, it was statistically similar with 20 kg ha^{-1} K_2O and, 60 kg ha^{-1} K_2O with zero lime and 20 kg ha^{-1} K_2O, and 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime at Gishe and Ago. The lowest nodule volume (0.00) per plant were recorded for the control plot and for all treatment combinations at Laften site, no nodule number were recorded to measure nodule volume (Table 9).

Table 9**.** Mean effective nodule number per plant (ENNPP) and nodule volume (NV) (ml) of soybean as affected by Potassium levels and lime rates at three sites in Gobu Sayo district in 2016 main cropping season.

			ENNPP				
Potassium levels	Location	GISHE		LAFTEN		AGO	
(kg ha-1)	Liming (t ha-1)	0	4.6	0	4.6	0	4.6
0		3.95^{jk}	45.30^{e}	0.00^{L}	0.87^{L}	0.57^{kL}	16.10^{h}
20		60.13^{c}	64.17^{b}	0.00^{L}	0.00^{L}	7.07^{ij}	18.93^{h}
40		27.27^{g}	68.10^{a}	0.00^{L}	0.00^{L}	7.20^{ij}	15.60^{h}
60		46.12^{e}	52.93^{d}	0.20^{L}	0.00^{L}	6.60^{ij}	25.00^{g}
80		41.20^{f}	69.70^{a}	0.00^{L}	0.00^{L}	8.80^{i}	24.00^{g}
CV (%)		10.00					
LSD (5%)		3.344					
			NV				
0		0.05^{e}	4.83^{bc}	0.00^{e}	0.00^{e}	0.00^{e}	4.33^{bcd}
20		5.33^{ab}	5.20^{ab}	0.00^{e}	0.00^{e}	5.00^{abc}	4.07^{cd}
40		3.57^{d}	4.93^{bc}	0.00^{e}	0.00^{e}	4.67^{bc}	4.33^{bcd}
60		5.30^{ab}	4.13^{cd}	0.00^{e}	0.00^{e}	4.33^{bcd}	5.00^{abc}
80		4.70^{bc}	5.95^{a}	0.00^{e}	0.00^{e}	4.70^{bc}	4.87^{bc}
CV (%)		18.60					
LSD (5%)		0.866					

Means followed by the same letters within column and rows for a variable are not significantly different at 5% P level.

4.2.7. Root volume (ml)

The combined analysis of variance showed that interaction of potassium fertilizer and lime rate has showed significant effect (P=0.001) on mean root volume of soybean over locations (Appendix Table 6). The highest root volume (23.07 ml) were obtained from the interaction of 80 kg ha^{-1} K_2O and zero lime while the lowest root volume (10.43 ml) was obtained for the control treatments both at Gishe site (Table 10).

4.2.8. Nodule fresh weight (ml)

The analysis of variance revealed that the interaction of potassium fertilizer and lime rates indicated that there was highly significant effect (P = 0.001) for nodule fresh weight (Appendix Table 5). The highest nodule fresh weight (4.53 ml) was recorded for the interaction of 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime applications at Ago site and the lowest value was obtained from the control and other treatment combination at Laften site (Table 10).

Table 10**.** Mean Root volume (RV) (ml) and nodule fresh weight (NFW) (gm) of soybean as influenced by interaction of Potassium and lime at three sites in Gobu Sayo district in 2016 main cropping season.

Potassium levels (kg ha-1)	Locations Lime(t ha-1)	**GISHE**		**LAFTEN**		**AGO**	
		0	4.6	0	4.6	0	4.6
	RV (ml)						
0		10.43^{h}	12.97^{defgh}	12.73^{defgh}	12.53^{efgh}	12.67^{defgh}	17.00^{b}
20		13.13^{defgh}	15.60^{bcd}	11.47^{fgh}	15.60^{bcd}	13.07^{defgh}	14.53^{bcde}
40		14.60^{bcde}	14.13^{bcdef}	13.60^{cdefg}	14.33^{bcdef}	17.00^{b}	13.47^{cdefg}
60		12.73^{defgh}	16.27^{bc}	10.73^{gh}	13.13^{defgh}	12.27^{efgh}	11.40^{fgh}
80		23.07^{a}	16.40^{bc}	12.33^{efgh}	12.33^{efgh}	14.93^{bcde}	16.67^{b}
CV (%)		10.8					
LSD (5%)		2.484					
	NFW(gm)						
0		0.18^{h}	1.73^{fg}	0.00^{h}	0.00^{h}	0.01^{h}	3.80^{b}
20		2.10^{ef}	2.53^{de}	0.00^{h}	0.00^{h}	1.90^{f}	3.28^{bc}
40		1.23^{g}	2.89^{cd}	0.00^{h}	0.00^{h}	1.82^{fg}	2.93^{cd}
60		1.85^{f}	2.13^{ef}	0.00^{h}	0.00^{h}	2.00^{ef}	4.53^{a}
80		1.80^{fg}	2.60^{de}	0.00^{h}	0.00^{h}	2.87^{cd}	3.43^{bc}
CV (%)		22.30					
LSD (5%)		0.55					

Means followed by the same letters within column and rows for a factor are not significantly different at 5% P level.

4.2.9. Nodule dry weight (gm)

The interactions of potassium and lime rates showed highly significant effect (P= 0.001) on nodule dry weight per plant (Appendix Table 5). The highest nodule dry weight (0.48 gm) was recorded for the interaction of 80 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime application at Gishe site while the lowest value was recorded for the control and other treatment combinations at Laften (Table 11) where no nodule was formed. From this result it can be concluded that plants having higher nodule dry weight were fixing the higher atmospheric N2 and accumulated higher dry matter than these with other combinations.

4.2.10. Shoot dry biomass weight per plant at mid flowering (gm).

The analysis of variance showed that the interaction of potassium and lime has highly significant effect (P=0.001) on shoot dry biomass weight (Appendix Table 8). The highest shoot dry biomass weight (16.20 gm) per plant at maximum vegetative growth stage was recorded for 40 kg ha^{-1} K_2O along with 4.6 t ha^{-1} lime application at Gishe and statistically in parity with 80 kg ha^{-1} K_2O with 0 lime, and 0 K_2O with 4.6 t ha^{-1} at Laften. On the other hand, the lowest values (3.62) were obtained from 60 kg ha^{-1} K_2O without lime and from absolute control treatment at Ago site (Table 11). It is believed that shoot dry biomass weight directly indicates maximum dry biomass accumulation of the plant at its maximum vegetative growth stages and maximum photosynthetic efficiency of the plant that enable to accumulate shoot dry matter at this stage.

.

Table 11**.** Mean Shoot dry biomass weight (SDBW) (gm) and nodule dry weight (NDW) (gm) of soybean as influenced by location, potassium levels and lime rates in 2016 main cropping season.

			SDBW(gm)				
	Location	GISHE		LAFTEN		AGO	
Potassium Levels (kg ha-1)	Liming(t ha-1)	0	4.6	0	4.6	0	4.6
0		7.55^{hijkL}	9.93^{defg}	8.27^{ghij}	14.80^{ab}	3.96^{n}	7.99^{hij}
20		10.23^{def}	10.40^{def}	6.63^{jklm}	9.33^{efgh}	7.08^{ijklm}	7.56^{hijk}
40		8.73^{fghi}	16.20^{a}	10.60^{cde}	11.33^{cd}	5.85^{klm}	5.89^{km}
60		8.40^{ghij}	10.47^{cde}	5.87^{km}	8.33^{ghij}	3.62^{n}	8.07^{hij}
80		8.53^{ghi}	14.27^{b}	15.53^{ab}	12.10^{c}	5.87^{klm}	8.19^{ghij}
CV (%)		10.20					
LSD (5%)		1.51					
			NDW(gm)				
0		0.05^{jk}	0.26^{de}	0.00^{k}	0.00^{k}	0.00^{k}	0.17^{fgh}
20		0.30^{cd}	0.35^{bc}	0.00^{k}	0.00^{k}	0.12^{hi}	0.21^{ef}
40		0.21^{ef}	0.40^{b}	0.00^{k}	0.00^{k}	0.05^{jk}	0.11^{i}
60		0.25^{de}	0.32^{c}	0.00^{k}	0.00^{k}	0.10^{ij}	0.18^{fg}
80		0.24^{e}	0.48^{a}	0.00^{k}	0.00^{k}	0.14^{ghi}	0.20^{ef}
CV (%)		23.4					
LSD (%)		0.053					

Means followed by the same letters within columns and rows for a factor are not significantly different at 5% P Level of significance.

4.2.11. Number of primary branches per plant.

Analysis of variance indicated that there was significant (P = 0.007) two way interaction between potassium and lime for number of primary branches per plant (Appendix Table 4). The highest number of primary branches was (5.87) recorded for the interaction of 80 kg ha^{-1} K$_2$O * with 4.6 t ha^{-1} lime while the lowest value (4.3) was obtained from the control treatment (Table 12). In addition, location alone showed highly significant effect (P = 0.001) on number of primary branches per plant. The highest number of primary branches (5.67) was recorded at Gishe site and the lowest (4.89) at Ago site (Table.12). The result is due to difference of environmental variations among the locations than the factors used.

Table 12. Mean number of primary branches of soybean as influenced by interaction of Potassium and lime rates in 2016 main cropping season.

Potassium levels kg ha^{-1}	lime rates (t ha^{-1})	0	4.6
0		4.30^{c}	5.44^{ab}
20		5.53^{a}	5.22^{ab}
40		5.76^{a}	5.04^{b}
60		5.52^{a}	5.60^{ab}
80		5.33^{a}	5.87^{a}
CV (%)		14.5	
LSD (5%)		0.73	

Means within column and rows for a factor followed by the same letters are not significantly different at 5% level of significance.

4.2.12. Tap root length (cm)

Mean taproot length of soybean didn’t show significant difference between main factors as well as their interaction (Appendix Table 6). But, locations showed significant difference for tap root length. Accordingly, the highest tap root length (15.94cm) was observed at Gishe site but it was statistically similar with Ago site while the lowest value was recorded at Laften. The significant difference in tap root lengths in this case could be attributed to environmental variations among the locations not due to the factors used sol treatments used in this experiment.

Table 13. Mean number of Primary branches (NPB), taproot lengths (TRL)(cm), and number of seed per pod(NSPP) as influenced by location in Gobu Sayo district in 2016 main cropping season.

		Measured Parameters		
LOCATION		NMB	TRL	NSPP
GISHE		5.67^{a}	15.94^{a}	2.34^{a}
LAFTEN		5.52^{ab}	14.54^{c}	2.23^{b}
AGO		4.89^{c}	15.52^{ab}	2.38^{a}
	CV (%)	14.5	9.2	9.8
	LSD (5%)	0.4	0.73	0.11

Means followed by the same letters within column for a factor are not significantly different at 5% level of significance.

4.3. Yield and Yield Components

4.3.1. Number of pods per plant

The interaction of potassium and lime showed that there was highly significant effect ($P = 0.001$) on number of pods per plant over locations (Appendix Table 7). The highest number of pods per plant (82.73) was recorded for 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime applications at Gishe farm while the lowest value (19.80) was recorded for the control treatments at Ago site (Table 14). This result indicated that interaction of potassium fertilizer and liming the soil has positive direct effect in increasing number of pods per plant. In line with this result, (Hirpa. *et al*., 2013) concluded that the effect of lime was greatest for pod number per plant with an average increase of 20.2% for the lime treated soil than for the untreated soil. Similar results were reported by Kisinyo *et al*. (2005) who suggested that lime application neutralizes soil acidity, reduces toxicity levels of Al, Fe and Mn and improves physiological, chemical and biological properties of soils; and also improves soil productivity by providing Ca and Mg and availability of P which in turn improve crop performance (Ponette *et al*., 1996). Especially, fixed P in acidic soil could be more available to plants consequently improves overall crop performance and yield.

Other studies have also shown that potassium application increase the number of pods as well as exerts a beneficial influence on retaining pods until harvest in soybean (Coale and Grove, 1990). This result is also in line with the observation of Mandal and Sikder (1999) who reported that growth and yield increased significantly with N availability, while P significantly increased the setting of pods and seeds. Eventually, from soil analysis results it was observed that there was a change of soil pH from very strongly acidic to slightly acidic after lime applied; consequently those fixed or unavailable nutrients especially phosphates and other exchangeable bases became more available to the crop and led to increased number of pods per plant.

4.3.2. Pod length (cm)

The analysis of variance showed that there was significant difference ($P= 0.025$) in pod length due to with interaction of potassium and lime rates over locations (Appendix Table 7). The highest pod length (4.67cm) was recorded for 4.6 t ha^{-1} lime applications without K_2O at Gishe, while the lowest value (3.91cm) was recorded for 20 Kg ha^{-1} K_2O without lime and 40 Kg ha^{-1} K_2O with 4.6 t ha^{-1} lime at Laften site.

Table 14. Mean pod numbers per plant (NPPP) and pod lengths (PL) (cm) of soybean as affected by the interaction of liming and potassium levels at three locations in Gobu Sayo district in 2016 cropping season.

			NPPP				
	Locations	GISHE		LAFTEN		AGO	
Potassium levels (kg ha-1)	liming(t ha-1)	0	4.6	0	4.6	0	4.6
0		37.47^{ijklmn}	40.30^{hijk}	41.50^{ghij}	33.70^{mn}	19.80^{O}	44.60^{efg}
20		39.67^{hijklm}	49.80^{cdef}	35.60^{jklmn}	41.27^{ghij}	34.51^{kLmn}	31.50^{n}
40		46.93^{defg}	53.93^{bc}	41.00^{ghij}	40.33^{hikj}	50.57^{cd}	37.00^{ijmn}
60		46.77^{defg}	82.73^{a}	42.40^{ghi}	44.27^{efgh}	39.80^{hijkL}	37.33^{ijklmn}
80		52.13^{bcd}	50.00^{cde}	43.93^{fgh}	42.70^{ghi}	33.93^{Lmn}	56.70^{b}
CV (%)		7.4					
LSD (5%)		5.21					
			PL(cm)				
0		4.33^{abcdef}	4.67^{a}	4.39^{abcd}	4.00^{defg}	$4.29^{abcdefg}$	4.37^{abcd}
20		4.35^{abcde}	4.17^{g}	3.91^{defg}	4.01^{defg}	4.24^{bcdefg}	4.24^{bcdefg}
40		3.93^{efg}	4.49^{abc}	4.17^{bcdefg}	3.91^{fg}	4.35^{abcde}	$4.33^{abcdefg}$
60		4.67a	4.47^{abc}	$4.29^{abcdefg}$	$4.31^{abcdefg}$	4.53^{abc}	$4.29^{abcdefg}$
80		4.39^{abcd}	4.63^{ab}	4.02^{defg}	4.15^{cdefg}	4.4^{abcd}	4.41^{abcd}
CV (%)		5.0					
LSD (5%)		0.34					

Means followed by the same letters within columns and rows for a factor are not significantly different at 5% level of significance.

4.3.3. Above ground dry biomass yield (kg ha^{-1})

The analysis of variance showed that the interaction of potassium levels and lime rates was highly significant effect (P=0.001) for above ground dry biomass over locations (Appendix Table 9). The highest biomass yield (10,508 kg ha^{-1}) was obtained from the interaction of 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime applications at Gishe and it was statistically insignificant with 60 and 20 kg ha^{-1} K_2O without lime at Laften and 80 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime application at Gishe. The lowest biomass yield (3701 kg ha^{-1}) was obtained due to application of 40 kg ha^{-1} K_2O without lime at Ago site (Table 15). From this result it was observed that above ground dry biomass yield has a direct positive relationship with the total grain yield of the crop. Because combination of 60 kg ha^{-}

^{1} K_2O with 4.6 t ha^{-1} of lime gave the highest biomass yield, as well as grain yield ha^{-1} and the lowest biomass yield was associated with the lowest grain yield for the interaction of 40 kg ha^{-1} potassium and zero kg ha^{-1} of lime, which is also confirmed by correlation analysis (r=0.793*) (Table 18). This result is most probably due to release of unavailable/fixed nutrients from strongly acidic soil with liming the soil and became available to the plants and, thus, contribute to above ground biomass growth of soybean.

In line with this result, there is a notion which indicates that phosphorous deficiency generally decreases plant biomass accumulation by limiting interception of photo-synthetically active radiation (PAR) rather reducing efficiency of conversion of PAR in to dry matter. Similar investigation by Zeidan (2007) and Erman *et al.* (2009) also indicated that increasing phosphorus levels from 0 to 60 kg P_2O_5 ha^{-1} increased the general biomass of lentil and field pea plants and decreased at 90 kg P_2O_5 ha^{-1} for field pea.

4.3.4. Harvest Index (HI)

Harvest index was highly (P= 0.001) influenced by the interaction of potassium and liming over locations (Appendix Table 9). In this study, 80 kg ha^{-1} K_2O without lime treatment gave the highest harvest index (0.42) at Laften site, but it was statistically non-significant with the interaction of 0 K_2O with 4.6 t ha^{-1} lime, 20 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime, 40 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime, 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime, and 60 kg ha^{-1} K_2O with 0 lime at the various sites. On the other hand, 4.6 t ha^{-}1 lime application without K_2O gave the lowest harvest index (0.20) at Laften (Table 15). The highest harvest index at higher level of K_2O contributed more dry matter partitioning to sink (seed) than to source (aboveground bio-mass), with a total of 42% to seed yield and the rest 58% to husk/straw yield.

Table 15. Mean above ground dry biomass yield (DBY) (kg ha^{-1}) and harvest index (HI) of soybean as influenced by location, potassium levels and lime rates at Gobu Sayo district in 2016 main cropping season.

		BYPH(kg ha^{-1})					
Potassium Levels	Locations	GISHE		LAFTEN		AGO	
(kg ha-1)	Liming(t ha-1)	0	4.6	0	4.6	0	4.6
0		7257^{gh}	8533^{cdefg}	8680^{bcdef}	7376^{fgh}	5519^{ij}	4756^{jkl}
20		9950^{abc}	8761^{bcdef}	9895^{abc}	7722^{efg}	3799^{kl}	4807^{jkl}
40		8222^{defg}	8555^{bcdef}	8333^{defg}	7477^{efgh}	3701^{L}	6276^{hi}
60		7800^{efg}	10508^{a}	9998^{ab}	8763^{bcdef}	3841^{kL}	5606^{ij}
80		8940^{bcde}	9475^{abcd}	5200^{ijk}	8333^{defg}	4656^{jkl}	4970^{ijk}
CV (%)		10.50					
LSD (5%)		1240.86					
		HI					
0		0.28^{ijklm}	$0.32^{bcdefghijkl}$	0.28^{ijklm}	0.20^{n}	0.27^{jklm}	0.38^{abcdef}
20		$0.30^{ghijklm}$	$0.36^{abcdefgh}$	0.29^{ijklm}	0.26^{lmn}	$0.35^{bcdefghi}$	$0.36^{abcdefgh}$
40		$0.31^{ghijklm}$	0.39^{ab}	0.24^{mn}	0.29^{hijklm}	$0.31^{eghijklm}$	0.38^{abcde}
60		$0.36^{abcdefgh}$	$0.34^{bcdefghij}$	0.26^{Lnmn}	$0.37^{abcdefg}$	0.39^{abcd}	0.39^{abc}
80		$0.32^{bdefghijkl}$	$0.32^{bcdefghijkl}$	0.42^{a}	0.26^{klmn}	0.28^{ijklm}	$0.33^{bcdefghijk}$
CV (%)		11.2					
LSD (5%)		0.059					

Means followed by the same letters within column and rows for a factor are not significantly different at 5% level of significance.

4.3.5. Number of seeds per pod

The results of analysis of variance showed that the variations in number of seeds per pod due to the main effect of potassium or liming the soil and their interaction were non-significant (Appendix Table 7). Although the main factors (K_2O or lime), and their interaction showed non-significant difference, the mean values of number of seeds per pod due to locations were significant (P= 0.04) (Table 13). The highest seed number per pod (2.38) was recorded at Ago site, which was statistically non-significant with Gishe site (2.34) while the lowest value (2.23) was obtained at Laften (Table 13). Most probably number of seeds per pod may vary due to genotype differences however, seeds per pod are less affected by external factors like fertilization when a single genotype is considered.

4.3.6. Hundred Seed Weight (gm)

The analysis of variance showed that there was highly significant (P= 0.001) effect on 100 seed weight (Appendix Table 7). The highest seed weight (23.33 gm) was recorded for 80 kg K_2O with 4.6 t ha^{-1} lime at Ago site and this result was in parity with the interaction of 40 kg K_2O and zero lime at the same site. The lowest seed weight (14 gm) was recorded at Laften site for the interaction of 20 kg K_2O with 4.6 t ha^{-1} lime (Table 16).

4.3.7. Total grain yield per hectare (kg ha^{-1})

The combined analysis of variance showed that mean grain yield of soybean was significantly influenced (P= 0.001) by the interaction of potassium fertilizer and liming the soil over locations (Appendix Table 9). It was observed that, 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime gave the highest grain yield (3642 kg ha^{-1}) at Gishe while the lowest yield (1014 kg ha^{-1}) was obtained from the control treatment at Ago site (Table 16). In line with this result, Shiferaw and Wassie *et al.* (2009) further substantiated by several reports that application of lime on acid soils is beneficial in situations where nutrients in the soil are made unavailable due to very low pH or high acidity.

In such a case, application of lime raises the soil pH and make essential nutrients to be in the available range to crop utilization. This also applies to potassium; because, according to Barkert *et al*. (1994), a significant increase in soybean yield has been observed as a function of increasing doses of K_2O. According to Malavolta *et al.* (1997), potassium is involved in osmotic processes, protein synthesis and maintenance the balance of solutes in and out of cells and also contributes to the metabolic reactions of cells. The potassium is also responsible by the opening and closing of stomata, membrane permeability and pH control. This causes the plant to become fully vegetative, ultimately maximizing reproductive development, and, thus, allowing the plant to produce at its yielding potential, but if acidic soils are already depleted of nutrients, lime application has limited value (Potash Institute, 1979). In line with this, Zhao *et al*. (2007) studied the effect of P, K and lime application on pasture and reported that K had no effect when applied alone but significantly increased pasture yield when applied with P. They further reported that lime had no effect on the yield of pasture. This implies that if the soils are acidic and depleted of essential nutrients at the same time, lime should be applied a long with organic or inorganic fertilizers or both. Grewal *et al.* (1994) have also that observed that soybean seed yield increased following application of up to 50 kg K_2O ha^{-1} when N was applied and up to 25 kg K_2O ha^{-1} in the absence of N in loamy sand soils of Punjab.

Table 16. Mean of hundred seed weight (HSW) (gm) and total grain yield (TGY) per hectare (kg ha^{-1}) of soybean as influenced by of potassium and lime rates at three sites in Gobu Sayo district in 2016 main cropping season.

		HSW(gm)					
	Location	GISHE		LAFTEN		AGO	
Potassium levels (kg ha-1)	Liming(t ha-1)	0	4.6	0	4.6	0	4.6
0		14.33^{gh}	16.33^{cdefgh}	15.00^{efgh}	14.67^{fgh}	14.00h	17.33^{bcde}
20		15.67^{cdefgh}	15.33^{defgh}	16.00^{cdefgh}	14.00^{h}	16.67bcdefg	18.00^{bc}
40		15.00^{efgh}	15.67^{cdefgh}	14.67^{fgh}	17.00^{bcdef}	19.00ab	17.67^{bcd}
60		14.00^{h}	16.33^{cdefgh}	15.33^{defgh}	15.33^{cdefgh}	16.67b	$17.00b^{cdef}$
80		16.33^{cdefgh}	15.67cdefgh	14.67fgh	16.33^{cdefgh}	14.67fgh	20.33a
CV (%)		8.30					
LSD (5%)		2.16					
			TYPH (kgha^{-1})				
0		2077^{jk}	2776^{de}	2459^{fgh}	1517^{m}	1014^{n}	2398^{ghi}
20		3077^{c}	3273^{bc}	2378^{ghi}	1989^{kL}	1357^{m}	2038^{jkl}
40		2658^{def}	3295^{b}	2046^{jkL}	2218^{ij}	1459^{m}	1930^{kl}
60		2859^{d}	3642^{a}	2588^{efg}	3250^{bc}	1855^{L}	2209^{ij}
80		2766^{de}	3072^{c}	2345^{hi}	2392^{ghi}	1372^{m}	1844^{L}
CV (%)		5.0					
LSD (%)		192.3					

Means followed by the same letters within column and rows are not significantly different at 5% level of significance.

Comparison of pooled mean yield

Comparison of pooled mean grain yield of soybean over the three locations and lime (4.6 t ha^{-1}) interaction with K_2O (60 kg ha^{-1}) over locations showed a mean grain yield of 3033.70 kg ha^{-1}, but mean grain yield over the location for inoculating the seed with legume fix bio-fertilizer strain was 2254 kg ha^{-1}. This result indicates that liming the soil plus potassium fertilizer application has more soybean yield advantages (34.56 %) over the standard check in the study area.

Table 17. Comparison of the pooled mean of total grain yield (kg ha^{-1}) of the standard check and lime and potassium application over locations.

Location	GISHE	LAFTEN	AGO	Pooled mean
standard check	2867	1969	1925	2254
K_2O + Lime	3642	3250	2209	3033
Yield Adv. (%)				34.56 %

Note: K_2O + Lime = interaction of 4.6 t ha^{-1} lime with 60 Kg ha^{-1} K_2O, Standard check = 50 kg P_2O_5 and inoculation of soybean seed with legume fix bio-fertilizer.

** New combination of factors are interaction of 4.6 t ha^{-1} lime with 60 kg ha^{-1} K_2O.

4.4. Correlation of some soybean yield and yield related parameters

Pair wise correlation analysis indicated strong and positive relation of parameters measured for soybean. Accordingly, there was a positive and highly significant correlation between nodule number per plant and nodule fresh weight (r= 0.555**), nodule dry weight (r=0.943**), and nodule volume (r= 0.736**), indicating that as nodule number per plant increases those parameters also increase. Besides, total nodule number per plant has also highly positive correlation with effective nodule number per plant (r=0.997**), pod number per plant (r= 0.499**), plant height (r= 0.512**), and total biomass yield per hectare (r=0.400**). Hence, the increase in nodule number per plant with increasing effectiveness of nodules is directly related to more fixation of N2 from the atmosphere and as a result, can contribute to effectiveness of photosynthetic capacity of the plant which is highly correlated with total yield per hectare. Number of primary branches is also positively correlated with total biomass yield per hectare and plant, height and, thus, plants accumulate higher biomass yield and produce more total yield per hectare. When plants increases in height, number of main/primary branches also positively increased and biomass yield per hectare is directly highly correlated because of crops having more branching number indicated that directly it contains more number of pods per branches which contributes for increased total yield per hectare.

From this result it is easily understood that total yield per hectare has highly significant correlation with dry biomass yield, effective nodule number, pod number per plant and biomass yield per hectare, contributing more to yield increment. As it can be seen from the correlation(Table 18) there is strong positive correlation between effective nodule number per plant and total yield per hectare (r= 0.670**). Pod number per plant has also strong positive correlation with both plant height (r= 0.619**) and total yield per hectare (r= 0.627**), as plant height increases number of main branches increases consequently pod number per plant also increases, which has direct positive relationship with total yield per hectare. Eventually, biomass yield per hectare has strong positive correlation with total yield per hectare (r= 0.793**), but it has negatively correlated with harvest index (r = -0.275*), indicating that as harvest index increased biomass yield decreased and vise-versa.

Table 18. Pearson correlation analysis for growth, yield and yield components of Soybean on acidic soils in Gobu Sayo District.

	NNPP	NFW	NDW	NV	RV	TRL	NMB	BDW	ENNPP	PNPP	PH	BYPH	HSW	HI	TYPH
NNPP															
NFW	0.554**	1													
NDW	0.943**	0.695**	1												
NV	0.736**	0.855**	0.816**	1											
RV	0.319*	0.313*	0.368*	0.377*	1										
TRL	0.282*	0.267*	0.321*	0.330*	0.133	1									
NMB	0.302*	0.003	0.242*	0.066	0.2838*	0.016	1								
BDW	0.352*	(0.085)	0.296*	(-0.058)	0.072	(-0.092)	0.37*	1							
ENNPP	0.997**	0.560**	0.948**	0.734**	0.329*	0.283*	0.287*	0.363*	1						
PNPP	0.499**	0.231*	0.463**	0.315*	0.412**	0.112	0.369*	0.310*	0.504**	1					
PH	0.512**	(-0.120)	0.368*	0.068ns	0.340**	0.028	0.543**	0.562**	0.508**	0.619**	1				
BYPH	0.400**	(-0.244)*	0.277*	(-0.127)	0.067	0.049	0.411**	0.397**	0.404**	0.456**	0.722**	1			
HSW	(-0.058)	(-0.307)*	0.021ns	0.191	0.262*	0.004	(-0.163)	(-0.310)*	(0.042)	(0.02291)	(-0.213)*	(-0.379)*	1		
HI	0.312*	0.505**	0.350*	0.453**	0.053	0.041	(-0.097)	(0.022)	0.308*	0.192	(-0.103)	(-0.275)*	0.067	1	
TYPH	0.669**	0.108	0.567**	0.214*	0.141	0.085	0.389**	0.434**	0.670**	0.627**	0.685**	0.793**	(0.295)*	0.292*	1

*(**)= highly significant, (*)= significant, (ns)= none significant, NNPP= Nodule number per plant, NFW= Nodule Fresh weight, NDW= Nodule dry weight, NV= Nodule volume, TRL= Tap root length, NMB= Number of main branches, BDW= Biomass dry weigh at mid flowering ENNPP= effective nodule number per plant, PNPP= Pod number per plant, PH= Plant height, BYPH= Biomass yield per hectare, HSW= Hundreds seed weight, HI= Harvest index, TYPH= Total grain yield per hectare.*

4.5. Grain quality data

4.5.1. Grain protein content

The results of grain protein content are presented in Table19 and 20. A statistically significant (P=0.006) variation was observed in seed protein content of soybean with different doses of potassium and lime, but their interaction was not significant. The highest protein content was recorded for 40 kg ha^{-1} K_2O. On the other hand, the lowest protein content in seed (32.42 mg/100gm) was recorded for the rate of 60 kg ha^{-1} K_2O. Concerning the effect of lime application, seed protein content of the control treatment (non-limed) was significantly higher than the limed treatment. This results indicates that liming acidic soil has negative effect by reducing the protein content of soybean seed. To the contrary, since potassium is a quality element, it has the capacity to increase grain protein content of soybean. This could be due to increased availability of phosphorous, potassium and other as compared to the pre-sowing soil condition. Similar result has been reported by Abbasi *et al*. (2010) for soil with high P sorption. On the other hand, Shahid *et al*. (2009) have reported that increasing levels of P had significant effects on protein contents of soybean

Table: 19. Mean seed protein content of soybean as affected by potassium application in Gobu Sayo District in 2016 main cropping season.

Treatments	Location	Protein mg/100 gm
K2O	GISHE	
0		34.06^{a}
20		35.10^{a}
40		35.65^{a}
60		32.42^{b}
80		35.62^{a}
CV (%)	4.2	
LSD (5%)	1.78	

4.5.2. Grain oil content of soybean

The analysis of variance showed that oil contents of soybean seed was statistically non-significantly affected by the application of K_2O and its interaction with lime (Table 20). But significant effect was observed for only lime rates. The highest seed oil content (18.76%) was recorded for non-limed and the lowest value (18.15%) for limed treatments. This result indicates that liming the soil has negative effect on oil content of soybean seed in the study area.

Table 20. Seed protein and oil contents of soybean as influenced by liming the soil in 2016

Lime rates(t ha^{-1})		Protein (mg/100gm)	Oil (%)
0		35.14^{a}	18.76^{a}
4.6		34.00^{b}	18.15^{b}
	CV (%)	4.2	3.3
	LSD (%)	1.12	0.47

Means followed by the same letters with in a column are not significantly different at $P<0.05$

4.6. Partial Budget Analysis

The results of this study revealed that the total grain yield significantly increased with the application of K_2O and lime and attained maximum value as compared with the control (Table 19). Accordingly, highest grain yield was recorded for 60 kg K_2O ha^{-1} with 4.6 t ha^{-1} lime application. As indicated in Table 21, the highest net benefit was obtained in response to the interaction of 60 kg K_2O ha^{-1} and 4.6 t ha^{-1}lime (29,728 ETB), with marginal rate of return (MRR) of 12.29, followed by 20 kg K_2O without lime, 20 kg K_2O with 4.6 t ha^{-1} lime, and 60 kg K_2O without lime with net benefit of 27,443, 26957, and 24981 Et Birr, respectively (Table 21). A dominance analysis was also performed to eliminate negative values. The highest marginal rate of return obtained showed that further earnings could be obtained by application of beyond 60 kg K ha^{-1}. According to the manual of CIMMYT (1988), for economic analysis, application of fertilizer with the marginal rate of return above the minimum level (100%) is economical. Thus, 60 kg K_2O ha^{-1} with 4.6 t ha^{-1} of lime was found to be economically feasible as compared to the other treatment combinations.

Generally, interaction of potassium fertilizer with lime for the production of soybean on acidic soil in Gobu Sayo district of western Ethiopia was economically feasible. Conversely, those combinations which showed negative MRR are not recommended for use by the farming communities in the study areas. In general, application of 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime gave the highest net benefit with MRR (12.29) were economically sound/feasible and recommended for soybean production in the study areas as well as for similar agro-ecologies.

Table 21. Partial Budget analysis for Soybean yield in Gobu Sayo district in 2016 cropping season

Treat. Combinations K_2O * Lime	Fertilizer cost	Trans & labor cost	TVC	TYPH kg ha-1	Adj.Yield 10%	T. Gross benefit (Yield*10)	Net benefit	MRR Ratio	%
T_1. 0 * 0	0	0	0	2077	1869.30	18693	18693	-	-
T_2. 20 * 0	200	50	250	3077	2769.30	27693	27443	35	3500
T_3. 40 * 0	400	100	500	2658	2392.20	23922	23422	-16.08	D
T_4. 60 * 0	600	150	750	2859	2573.10	25731	24981	6.24	624
T_5. 80 * 0	800	200	1000	2766	2489.40	24894	23894	-4.35	D
T_6. 0 * 4.6	0	2300	2300	2776	2498.40	24984	22684	-0.58	D
T_7. 20 * 4.6	200	2300	2500	3273	2945.70	29457	26957	21.37	2137
T_8. 40 * 4.6	400	2400	2800	3295	2965.50	29655	26655	-1.00	D
T_9. 60 * 4.6	600	2450	3050	3642	3277.80	32778	29728	12.29	1229
T_{10}. 80 * 4.6	800	2300	3100	2392	2152.80	21528	18428	-226	D

where: TYPH (total yield per hectare),
MRR (Marginal rate of return), TVC (Total variable cost)

5. SUMMARY AND CONCLUSIONS

Laboratory analysis results of pre-sowing soil samples revealed that the soil pH was very strongly acidic for Gishe and Laften sites, while strongly acidic for Ago site. This result showed phosphates and some macronutrients and micronutrients were not in available forms/deficient to the crops due to fixation nature of the nutrients and other related constraints in acidic soils (low pH). The overall post-harvest soil analysis results showed that for most soil analyzed parameters such as available phosphorous, exchangeable bases, soil pH, organic carbon, total nitrogen, and cation exchange capacity considerably increased while compared to pre-sowing soil conditions as a result of K_2O and lime treatments.

Therefore, there was a significant increase in growth and yield parameters of soybean with application of lime. Highly significant (P=0.001) differences were observed among the treatments for days to 50% flowering, days to physiological maturity, plant height, nodule volume, root volume, nodule fresh and dry weights, total nodule number and number of effective nodules per plant, shoot dry biomass yield per plant, dry biomass weight per hectare, number of pods per plant, pod length, hundred seed weight, total grain yield per hectare, and harvest index due to interaction of lime rates and potassium fertilizer levels. The highest soybean grain yield (3642 kg ha^{-1}) was obtained from the interaction of 60 kg K_2O ha^{-1} with 4.6 t ha^{-1} lime applications at Gishe while the lowest yield (1014 kg ha^{-1}) was obtained at Ago site from the control treatment. Besides its economic feasibility, application of 60 kg ha^{-1} K_2O with 4.6 t ha^{-1} lime has a yield advantages of 34.56 % over the standard check. Therefore, application of lime with K_2O to acidic soils increases availability of nutrients, especially phosphates, exchangeable bases, and total nitrogen as well as organic matter and organic carbon in the soil, which are very crucial for betterment of crop performance and yield.

In general, liming the soil plus potassium fertilizer application was useful in the study areas and similar agro-ecologies. Through the interaction of potassium and liming increased soybean yield, grain yield of the crop was still low as compared to the global average and its potential yield. Even though maximum effect of lime on acidic soil is difficult to estimate with in a single season, it could be recommend that correcting soil acidity and improving soybean yield on acidic soil could be possible in one growth season, even before the soil reaction comes to the desired level. Besides, potassium 40 kg ha^{-1} K_2O, followed by 80 and 20kg ha^{-1} K_2O application respectively significantly affected seed protein contents, but K_2O interaction with lime has negative effect on both protein and oil contents of soybean seeds.

Hence the present findings show that lime application has negative effect in reducing both protein and oil contents on soybean seed. However, reclamation of the soil physical and chemical properties and biological activities of a soil has great importance in increasing crop production and productivity for the succeeding crops. As the present experiment was done for a season with a single crop variety, evaluation of the response of different maturity groups of soybean varieties inoculated with different *Bradyrhizobium japonicum* strains and their response to liming and potassium application needs further investigation to come up with a conclusive recommendation.

6. REFERENCES

Abbasi, K. M., Manzoor, M. and Tahir, M.M. 2010. Efficiency of *Rhizobium* inoculation and P fertilization in enhancing nodulation, seed yield, and phosphorus use efficiency by field grown soybean under hilly region of Rawalakot Azad Jammu and Kashmir, Pakistan. *Journal of Plant Nutrition,* **33**:1080–1102.

Abdenna, D. Negassa, C.W. and Tilahun, G. 2007. Inventory of Soil Acidity Status in Crop Lands of Central and Western Ethiopia. "Utilization of diversity in land use systems: Sustainable and organic approaches to meet human needs" Tropentag, October 9-11, 2007, Witzenhausen.

Abegaze, A., 2008. Indigenous Soil Nutrient Supply and Effects of Fertilizer Application on Yield, N, P and K Uptake, Recovery and Use Efficiency of Barley in Three Soils of Teghane, the Northern Highlands of Ethiopia. *African Journal of Agriculture*. Research, **3:**688-699.

Abel S, Ticconi CA, Delatorre CA (2002). Phosphate sensing in higher plants. *Physiol. Plantarum,* **115**(1): 1-8.

Achalu, C., Heluf, G. Kibebew K, and Abi, T. 2012. Response of barley to liming of acid soils collected from different land use systems of western Oromia, Ethiopia. Journal of *Bio-diversity and Environmental Sciences,* **2(5):** pp 37-49.

Adel MS, Thomas RS (1994). Soybean nitrogen fixation and growth as affected by drought stress and potassium fertilization. *J. Plant Nutr*. **17 (7)**: 1193-1203.

Adjei, M.B. and Chambeiss, C.G. 2002. Nitrogen fixation and inoculation of forage legumes. An electronic publication of Agronomy Department. University of Florida. pp 1-10.

Amare, Belay; 1987. Research Programs of IAR (Institute of Agricultural Research).Addis Ababa, Ethiopia.

Annadurai, K., Seshadri, P. and Palaniappan, S. 1994. Influence of potassium levels on yield and oil content in sunflower-soybean sequence. *Journal of Potassium Research* **10(2):** 124-129.

Baque, M.A., M.A. Karim, A. Hamid and H. Tetsushi. 2006. Effects of fertilizer potassium on growth, yield and nutrient uptake of wheat (Triticcum aestivum) under water stress conditions. *South Pacific Studies,* **27(1):** 25-35.

Barkert, C.M. and Sfredo, G.J. 1994. Fertilizing tropical soils for soybean. pp. 175-200. *In Tropical Soybean: Improvement and Production.* Brazilian Agricultural Research Enterprise, National Soybean Research Center, Plant Production and Protection Series, 27. FAO, Rome.

Bejiga, G., 2004. Current Status of Food Legume Production and Use of Biological Nitrogen Fixation in Ethiopia. In: Symbiotic Nitrogen Fixation Prospects for Enhanced Application in Tropical Agriculture, Serraj, R, (Ed.), Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India, pp: 263-265.

Bekere, W. and Hailemariam A. (2012). Influences of Inoculation Methods Phosphorus Levels on Biological Nitrogen Fixation attributes and Yield of Soybean (*Glycine max L.)* at Haru, Western Ethiopia. *Am. J. Plant Nutr. Ferti. Technol.* **2(2):**45-55.

Bekere, W., Kebede T. and Dawud J. (2013). Growth and Nodulation Response of Soybean (G*lycin max* L.) to Lime, *Bradyrhizobium japonicum* and Nitrogen Fertilizer in Acid Soil at Melko, South Western Ethiopia. *Int. J. Soil sci.* **8 (1):** 25-31.

Bekere, W., Wolde-meskel, E. and Kebede, T. 2012. Growth and nodulation response of soybean (*Glycine max* L) to *Bradyrhizobium* inoculation and phosphorus levels under controlled condition in South Western Ethiopia. *African Journal of Agricultural Research*, **7(30):** 4266-4270.

Bolan, N.S., M.J. Hedley, and R.E.White.1991.Process of soil acidification during nitrogen cycling with emphasis on legume based pastures. Plant and soil **134**:53-63.

Brady, N.C. and R.R. Weil. 2002. *The Nature and Properties of Soils* (13th Ed). Pearson.

Bulter, T.J. and Evers, G. 2004. Inoculation, nodulation, nitrogen fixation and transfer. Texas cooperative extension (press).

Chang, E.T., Lee, V.S., Canchola, A.J., Clarke, C.A., Purdie, D.M., Reynolds, P, Anton-Culver, H., Bernstein, L.,Deapen, D., Peel, D., Pinder, R., Ross, R.K., Stram, D.O., West, D.W.,

CIMMYT, 1988. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition, *Mexico. D.F conference held at International Livestock Centre for Africa (ILCA),* 31 August - 4 September, 1987.

Coale, F.J. and Grove, J.H. 1990. Root Distribution and Shoot Development in No-Till Full Season and Double-Crop Soybean. *Agronomy Journal*, **82**, 606-612.

CSA (Central Statistical Agency), 2012. Report on Area on and Crop Production Forecast for major crops .Statistical Bulletin 505. Addis Ababa, Ethiopia.

CSA (Central Statistical Agency), 2015. Report on Area and Crop Production Forecast for major crops. Addis Ababa, Ethiopia.

Desta, B.1988. Soil Science Research in Ethiopia: A Review. Proceedings of the first Soil Science Research Review Workshop, 11-14 February 1986, Addis Ababa, IAR, Addis Ababa. Pp

Ellafi, A.M., A. Gadalla and Y.G.M. Galal, 2011. Bio-fertilizers in action: Contributions of BNF in sustainable agricultural ecosystems. Int. Sci. Res. J., **3**:108-116.

Erman, M., B. Yildirim, N. Togay and F. Cig, 2009. Effect of phosphorus application and *Rhizobium* inoculation on the yield, nodulation and nutrient uptake in field pea (*Pisum sativum* sp .*arvense* L.). *Journal of Animal and Veterinary Advances*, **8(2):**301-304.

Esther R., Ken E. Giller, 2013. N2 Africa progress report putting nitrogen fixation to work for smallholder farmers in Africa (progress report). Milestone reference number: S 1.2.1.

Fassil, K. and Charles Y.2009. Soil Fertility Status and Numass Fertilizer Recommendation of Typic Hapluusterts in the Northern Highlands of Ethiopia.

Fassil, K.2008. Potassium Status in the Soils of Highlands of Ethiopia and the Need for Potash Fertilizer in Abstract and Congress Program; Addis Ababa, Ethiopia, Pp 37-38.

Fernandez, F. (2012) Corn, Soybean Showing Signs of Potassium Deficiency. Corn and Soybean Digest Newsletter.

Friesen, D.K.,M.H.Miller ,and A.S.R.Juo.1980.Lime phosphate-zinc interaction into two Nigerian utisols: II. Effects on maize root and shoot growth. Soil Sci.Soc.Am.J.44:1227-1232.

Gangasuresh, P., Muthuselvi, V., Muthulakshmi, E., Muthumari, S. and Maniammal, G. 2010. Synergistic Efficiency of Phosphate Solubilizer Associated with Nitrogen Fixer on the Growth of Soybean (*Glycine max*). *International Journal of Biological Technology*, **1(2)**: 124-130.

Gardia, M. B. 1980. Effects of potassium and giberellic acid on stem growth of whole sunflower plants. *Physiology Plant* **49**:443–448

George, R. and Michael S. 2002. Potassium for crop production (http://www.extension.umn.edu/agriculture/nutrientmanagement/potassium/potassim-for crop-production/) Accessed on April 17, 2017.

Giller, K. 2001. Nitrogen Fixation in Tropical Cropping Systems, Ed 2nd, CABI, Wallingford. Glass, A.D.M. 1983. Regulation of ion transport. Annu. Rev. *Plant Physiol.* ***34****:311–326*

Golbitz, P. (2007). *Soya and Oilseed Bluebook*, Soya tech, Inc., Bar Harbor, ME., Graham, and MJ. Graham, M.J., Nickell, C.D. & Rayburn, A.L. (1994). Relationship between genome size and maturity group in soybean. *Theoretical and Applied Genetics*, **88**: 429-432.

Grewal, H. S., Kolar, J. S., Dalip Singh and Singh, D. 1994. Effect of potassium and nitrogen on growth and yield of soybean (Glycine max L.) Merr. *Journal of Potassium Research* **10**(2): 173-177.

GURMU, F. 2007. Participatory Varietal Selection of Soybean *[(Glycine max* (L.) Merrill] Varieties in Umbullo Wacho and Beresa Watersheds in the Southern Region. Operational Research and Capacity Building for Food Security and Sustainable Livelihoods: Proceedings of Irish Aid Supported Operational Research Project Review Workshop.

GURMU, F. 2010. Overview of Soybean Research in Ethiopia. Hawassa: SARI.

Haru, A. and Ethiopia, W. 2012. Influences of inoculation methods and phosphorus levels on nitrogen fixation attributes and yield of soybean (*Glycine max* L.). *American Journal of Plant Nutrition and Fertilization Technology*, **2(2):** 45-55.

Hasan, R. 2002. Potassium status of soils in India. Better Crops Intern **16**:3–5

Hegstad, H.G. (2008) Nutritional and Health Benefits of Soybean. Soy Protein Quality Evaluation Report. Food and Agriculture Organization of the United Nations. Food and Nutrition, Rome, Paper No. 71.

Hillard, J.B., V. A. Haby F.M. Hons.1992. Annual ryegrass response to limestone and phosphorous on an Ultisol. *Journal of plant nutrition* **15(8):**1253-1268.

Hiller, L.K. (1995) Foliar Fertilization Bumps Potato Yields in Northwest: Rate and Timing of Application, Plus Host of Other Considerations, Are Critical in Applying Foliars to Potatoes. *Fluid Journal*, **10**, 28-30.

Hirpa, L., Nigussie-D., Setegn G., Geremew B., and Firew M., 2013. Response to Soil Acidity of Common Bean Genotypes (*Phaseolus vulgaris* L.) Under Field Conditions at Nedjo, Western Ethiopia

Hoeft, R.G., Nafziger, E.D., Johnson, R.R. and Aldrich, R. 2000. Modern Corn and Soybean Production, MCSP Publications, USA, pp 353.

Holzmueller, E.J., Jose, S., Jenkins, M.A. 2007. Influence of calcium, potassium, and magnesium on Cornus florida L. density and resistance to dogwood anthracnose. *Plant Soil*, **290:** 189–199.http://www.asaimsea.com

IFPRI, 2010. Fertilizer and Soil Fertility Potential in Ethiopia: Constraints and opportunities for enhancing the system.

Jackson, M.L.1967.Soil Chemical Analysis. Prentice Hall, Inc., Engle Wood Cliffs. New Jersey.183-204p.

Jackson, M.L.1967.Soil Chemical Analysis. Prentice Hall, Inc., Engle Wood Cliffs. New Jersey.183-204p.

Jodie, N. H. and Peter, B. 2000. Selection of phosphate solubilizes for use as bio-fertilizers. pp. 115. *In*: Kennedy, I. and Copeland, L. (eds.), *8th International Symposium on Nitrogen Fixation with Non Legumes*. 3-7 December 2000. The University of Sydney, Australia.

Juff, B.2014.Role of potassium: The Samuel Roberts Noble Foundation,

(https://www.noble.org/ag/s oils/roleofpotassium) Accessed on April 17, 2016.

Juo.A.S.R., and A.Manu.1996. Chemical dynamics in Slash-and-burn agriculture .Agric.Ecosyst.Environ.**58**:49-60.

Kamara, A.Y., Kwari, J., Ekeleme, F., Omoigui, L. and Abaidoo, R. 2010. Effect of Phosphorus Application and Soybean Cultivar on Grain and Dry Matter Yield of Subsequent Maize in the Tropical Savannas of North-Eastern Nigeria. *African Journal of Biotechnology*, **7(15):** 2593-2599.

Kim, H. Tan. 2010. Principles of soil environmental chemistry. CRC press. New York.

Kinekar, J. 2010. Potassium fertilizer situation in India: Current use and perspectives *Agricultural Science*: **24** (11-):6

Kisinyo, P.O., C.O. Othieno, J.R. Okalebo, M.J. Kipsat, A.K. Serem and D.O. Obiero 2005. Effects of lime and phosphorus application on early growth of Leucaenain on acid soils. *Afr. Crop Sci. Conf. Proc.*, **7:** 1233-1236.

Kisinyo, P.O., S.O. Gudu, C.O. Othieno, J.R. Okalebo and P.A. Opala (2012). Effects of lime, phosphorus and rhizobia on Sesbania sesban performance in a Western Kenyan acid soil. *Afr. J. Agric. Res***., 7:** 2800-2809.

Kumar, R. Chandra R (2008). Influence of PGPR and PSB on rhizobium Leguminosarum Bv. Viciae competition and symbiotic performance in lentil. *World J. Agric. Sci*., **4(3)**: 297-301.

Lambers, H., Shane, M.W., Cramer, M.D., Pearse, S.J. and Veneklaas, E.J. 2006. Root Structure and Functioning for Efficient Acquisition of Phosphorus: Matching Morphological and Physiological Traits. *Annual Botanical*, **98**: 693-713.

Leidi, E.O. and Rodriguez-Navarro, D.N. 2000. Nitrogen and Phosphorus Availability Limit N2 Fixation in Bean. *New Phytologist*, **147(2)**: 337-346.

Malavolta, E., Vitti, G.C., and Oliveira, S.A., 1997. Avaliac¸ ão do estado nutricional das plantas: princípios e aplicac¸ ões. Revista atual. Piracicaba: POTAFÓS **2:** 319, Func¸ ões, Cap. **3:** 76–77.

Mandal, R. and B. C. Sikder, 1999. Effect of nitrogen and phosphorus on growth and yield of mung bean grown in saline soil of Khulna, Bangladesh. *J. Phytological Res*. **12**:85-88.

Mengel, K. and Kirkby, EA. 2001. *Principles of Plant Nutrition*, 5th ed. Kluwer Academic Publishers: Dordrecht, the Netherlands, pp. 481–509.

Mesfin, A. 2007. Nature and Management of Acid Soils in Ethiopia. Alamaya University of Agriculture. 18 pp.

Murphy, HF. 1968. Reports on fertility status of some soils and other data on soils of Ethiopia College of Agriculture HSIU, Addis Ababa, Ethiopia; Experiment Station Bulletin No.44.

Negi, S., R.V. Singh and O.K. Dwivedi (2006). Effect of bio-fertilizers, nutrient sources and lime on growth and yield of garden pea. *Legume Res*., **29**: 282-285.

Nekesa, A., 2007. Effect of Minjingu phosphate rock and agricultural lime in relation to maize, groundnut and soybean yields on acid soils of western Kenya. MSc Thesis, Moi University, Eldoret, Kenya.

Nelson, K.A., Motavalli, P.P. and Nathan, M. (2007) Mobility of Iron and Manganese within Two Citrus Genotypes after Foliar Applications of Sulfate and Manganese. *Journal of Plant Nutrition,* **30**, 1385-1396.

Olsen, R., Cole, S., Watanabe, F. and Dean, L. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture Circ. 939.

Olufajo, O.O. and U.R. Pal, 1991. Row spacing and plant density effects on the agronomic performance of soybean in sub-humid tropical environments. *Samaru J. Res. Agric.,* **8**: 65-73.

Oluwatoyinbo, F.I., Akande M.O. and. Adediran J.A. 2005. Response of Okra (Abelmoschus *esculentus*) to Lime and Phosphorus Fertilization in an Acid Soil. *World Journal of Agricultural Sciences* **1(2):**178-183,

Pedersen, P. 2015. When do we need to inoculate our soybean seeds? Integrated Crop Management. Iowa State University. Paper 1559. Perrenoud, S. 1990. Potassium and Plant Health, 2nd ed.; International Potash Institute: Bern, Switzerland, pp. 8–10.

Ponette, Q., S. Belkacem and C.Nys, 1996. Ion dynamics in acid forest soils as affected by addition of Ca fertilizers. *Geoderma*, **71**:53-76.

Potash and Phosphate Institute. (1979). Soil Fertility Manual. Atlanta, Georgia.

Prasad, R.1992, Effect of liming on yield of soybean and nutrient availability in acidic soil. J. *Indian Soc. Soil Sci***. 40**: 377-379.

Rahman, L., 1982. Cultivation of soybean and its uses. City press, Dhaka, pp: 5-7.

Rahman, M.A., M. Bodruzzaman, A.J. M.S. Karim, M.A. Razzaque and S.A. Mesiner .2001. Effect of lime and Phosphorous on soil pH, available P in soil and yield of wheat in acid soil of Dinajpur. Annals of Bangladesh Agriculture **10(1).**

Rengel, Z. and Damon, PM. 2008. Crops and genotypes differ in efficiency of potassium uptake and use. *Physiology of Plant,* **133:** 624–636

Rice, W.A., G.W. Clayton, P.E. Olsen and N.Z. Lapwayi, 2000. Rhizobia inoculants formulations and soil pH influence on field pea nodulation and nitrogen fixation. Con. *J. Soil Sci.,* ***80****:395-400.*

Ristow, P.L., J. Foster, Q.M. Ketterings (2010). Lime Guidelines for Field Crops; Tutorial Work book. Department of Animal Science. Cornell University, Ithaca NY. 47 pages.

Samanta, M., P.B.S. Bhadoria and B.C. Ghosh. 1994. Effect of lime and phosphorus on phosphate availability and yield of ground nut *(Arachis hypogaea*) in Oxisol. *Indian Journal of Agronomy*. **39(4):** 692-693.

Samavat, S., Mafakheri, S. and Shakouri, M. J. 2012. Promoting Common Bean Growth and Nitrogen Fixation by the Co-Inoculation of *Rhizobium* and *Pseudomonas fluorescens* Isolates. *Bulgarian Journal of Agricultural Sciences*, **18(3):** 387-395.

Samia, Y.O., Ahmed, W.M.A. and Mariod, A. A. 2012. Effect of Urea, NPK and Compost on Growth and Yield of Soybean (*Glycine max* L.), in Semi-Arid Region of Sudan ISRN Agronomy.

Sanchez, P.A.and J.G. Salinas.1981.Low input Technology for managing Oxisols and Ultisols in Tropical America.Adv.Agron.34:279-406.

Schlede, H. 1989. Distribution of acid soils and liming materials in Ethiopia. Ethiopian Institute of Geological Surveys, Ministry of Mines and Energy. Addis Ababa, Ethiopia.

Shahid, M.Q., Saleem, M.F., Khan, H.Z. and Anjum, S.A. 2009. Performance of Soybean (*Glycine max* L.) under Different Phosphorus Levels and Inoculation. *Pakistan Journal of Agricultural Sciences*, **46(4):** 237-241.

Silva, SR., Barros, NF, Novais, RF. and Pereira, PRG. 2002. Eucalypt growth and nutritional efficiency of potassium under soil compaction. Revista Brasileira de Ciência do Solo, **26**: 4-1002.

Sinclair, T.R. and Vadez, V. 2002. Physiological traits for crop yield improvement in low N and P environments. *Plant and Soil*, **245**: 1-15.

Sinclair, T.R., L.C Purcell, and V.R. Serraj., 2001. Nitrogen fixation activity of soybeans under soil conditions. *Agronomy Journal*, **21**: 653-657.

Slattery, B. Hollier, C. 2002. The Impact of Acid Soils in Victoria. Report for the Department of Natural Resources and Environment, Goulburn Broken Catchment Management Authority, North East Catchment Management Authority. Department of Natural Resources and Environment, Rutherglen Research Institute.

Slattery, W. J. and Coventry, D. R.2000. Response of wheat, triticale, barley, and canola to lime on four soil types in north-eastern Victoria. *Aust. J. Exp. Agric.* **33:** 609- 618.

Slattery, W. J., Edwards, D. G., Bell, L. C., Coventry, D. R., and Helyar, K. R. 1998. Soil acidification and the carbon cycle in a cropping soil of north-eastern Victoria. *Australian Journal of Soil Research* **36**: 273-290.

Slattery, W.J, Ridley AM, Windsor SM 1999. Ash alkalinity of animal and plant products. *Australian Journal of Experimental Agriculture* **31**: 321-324.

Smith, D.L. and D.J. Hume. 1987. Comparison of assay methods for N2 fixation utilizing white bean and soybean. *Can. J. Plant Sci.,* **67**: 11-19.

Sood, R.D. and R.K. Bhardwaji.1992. Effect of liming and phosphorus fertilization on P fractions in an acid Alfisol. *J. Indian Sco. Soil Sci*.40: 299-301.

Staton, M. 2014. Identifying and responding to soybean inoculation failures. Michigan State University.

Taye, B. (2007): An overview of acid soils their management in Ethiopia paper presented in the third International W0rkshop on water management (Wterman) project, September,19-21, 2007, Haromaya, Ethiopia.

Taye, B. 2008. Estimation of Lime Requirement. Training Manual for Regional Soil Testing Laboratory Heads and Technicians. National soil Testing Center, Ministry of Agriculture and Rural Development.

Tiwari, S.P., Joshi O.P., Vyas, A.K. and Billore, S.D. (2001) Potassium Nutrition in Yield and Quality. 307-320.

Uchida, R. 2000. Essential nutrients for plant growth: Nutrient functions and deficiency symptoms. Plant nutrient management in Hawaii’s soils. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa: 31-55 pp.

Urgessa, T., 2015. Empirical Review of Production, Productivity and Marketability of Soya Bean in Ethiopia. Oromia Agricultural Research Institute, Haro Sabu Agricultural Research Center, Kellem Wollega, Dale Sadi District, P. O. Box 10 Haro Sabu, Ethiopia. *Genetics,* **88:** 429-432.

Wafaa, W.M., El–Marakby, A.M., Abdel–Halim, A.A. and Afaf, M.T. 2002. Evaluation of performance and stability of some soybean genotypes under different environments. Annals of Agricultural Science, **47(2):** 621–640.

Wang, J., Raman, H., Zhang, G. Mendham, N. and Zou, M. 2006. Aluminum tolerance in barely (Horidium vulgarie L.): Physiological mechanisms, genetics and screening methods. Journal of Zhejiang University Science. **7:** 769-787

Wassie, H. Shiferaw, Boke, and Kelsa Kena., 2009. Integrated soil fertility management options for Sustainable Crop Production: Review of Research Findings from Southern Regional State of Ethiopia. Paper presented on the 10th anniversary conference of Ethiopian Society of Soil Science (ESSS), 26-27 March 2009, Addis Ababa, Ethiopia.

Wassie, H. W. and Shiferaw, B., 2011. Response of Irish Potato (Solanum tuberosum) to the Application of Potassium at Acidic Soils of Chencha, Southern Ethiopia. *Int. J.* Agric. Biol., **13**: 595–598.

WHO (world health organization), Technical Report Series (2003) 916. Report of a Joint WHO/FAO Expert Consultation.

Wijnands, J.H.M., Dufera Gurmessa, J.C.M. Lute and E.N. van Loo, (2011). Ethiopian soya bean and sunflower value chain: Opportunities and challenges. Wageningen. 130P.

Williams, J. and Smith, S.G. 2001. Correcting potassium deficiency can reduce rice stem diseases. *Better Crops,* **85**: 7–9.

Wold-maskel, E. (2007). Genetic Diversity of Rhizobia in Ethiopian Soils: Their Potential to Enhance Biological Nitrogen Fixation (BNF) and Soil Fertility for Sustainable Agriculture. *Ethiopian Journal of Biological Sciences* **6 (1):** 77-95.

Wright, W., Ziogas, A. and Horn-Ross, P. L. (2007) Diet and Risk of Ovarian Cancer in the California Teachers Study Cohort. *American Journal of Epidemiology,* **165**, 801-813.

Yoseph, T. and Worku, W. 2014. Effect of NP Fertilizer Rate and Bradyrhizobium Inoculation on Nodulation, N-Uptake and Crude Protein Content of Soybean [Glycine Max (L.) Merrill], At Jinka, Southern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, **4(6):** 49-54.

Zeidan, M.S., 2007.Effect of organic manure and phosphorus fertilizers on growth, yield and quality of lentil plants in sandy soil. Research Journal of Agriculture and Biological Sciences, **3:** 748-752.

Zhao, J. Michalk, LY. Wen Y, Kemp KR, Du, G and Helen N (2007): Effect of phosphorus, potassium and lime application on pasture in acidic soils in Yunnan province, China. of Agri. Res., **50:** 523-535.

7. APPENDIX

Appendix Table 1. Post-harvest soil results of the three locations for exchangeable bases (Ca, Mg, K) at Gobu Sayo district in 2016.

Loc.	GISHE	LAFTEN	AGO	GISHE	LAFTEN	AGO	GISHE	LAFTEN	AGO	
TRT	Ca	Ca	Ca	Mg	Mg	Mg	K	K	K	Na
T4	10.20	10.70	11.50	22.60	8.10	8.90	1.48	1.28	0.83	-
T11	13.10	11.90	12.70	8.60	6.50	4.50	1.41	1.33	0.50	-
T6	13.10	21.10	16.10	21.00	12.20	21.60	1.43	1.39	0.65	-
T5	12.50	12.80	9.60	18.40	16.00	12.90	1.46	1.43	0.64	-
T9	14.80	22.20	13.90	19.10	9.20	32.70	1.47	1.38	0.74	-
T2	11.20	8.70	10.80	25.80	8.80	9.00	1.41	1.10	0.88	-
T10	12.90	21.10	15.60	21.60	10.20	23.40	1.36	1.20	1.04	-
T3	12.30	11.40	12.20	17.60	14.40	11.50	1.32	1.36	0.98	-
T7	13.00	18.70	14.20	25.30	2.20	33.50	1.38	1.30	0.86	-
T1	10.50	9.70	12.90	5.22	7.43	5.60	0.88	0.64	0.72	-
T8	14.20	21.90	17.20	18.30	11.70	25.20	1.28	1.32	1.00	-

Where: Ca (Calcium), Mg (Magnesium), K (Potassium).

Appendix Table: 2. Post-harvest soil results of the three locations for power of hydrogen(pH), percent of organic carbon (%OC), and cation exchange capacity (CEC) at Gobu Sayo district in 2016.

Loc.	GISHE	LAFTEN	AGO	GISHE	LAFTEN	AGO	GISHE	LAFTEN
Trt.	pH	pH	pH	(%OC)	(%OC)	%OC	CEC	CEC
T4	4.92	5.1	4.96	3.82	3.29	2.42	21.40	24.40
T11	4.95	4.93	5.25	3.54	3.13	2.54	21.40	22.48
T6	5.5	5.81	5.53	3.38	3.28	2.61	27.68	24.40
T5	4.91	4.94	4.99	3.70	3.34	2.67	23.52	18.40
T9	6.26	5.92	5.56	3.48	2.89	2.38	28.40	25.70
T2	4.89	4.95	4.94	3.62	3.27	2.20	20.40	14.40
T10	5.71	5.57	5.6	3.49	3.11	2.47	26.86	28.40
T3	4.95	4.98	4.84	3.67	2.88	2.35	24.40	14.40
T7	5.86	5.65	5.51	3.29	3.14	2.35	25.06	22.40
T1	4.91	4.95	4.9	3.23	3.30	2.59	18.40	14.40
T8	5.89	6.12	5.8	3.69	3.39	2.31	22.44	26.40

Where: pH (power of hydrogen), %OC (Organic Carbon), CEC (Cation Exchange Capacity).

Appendix Table: 3. Post-harvest soil results of the three locations for percent of Organic matter, percent of Total nitrogen, and Available phosphorous at Gobu Sayo district 2016.

Location	GISHE	LAFTEN	AGO	GISHE	LAFTEN	AGO	GISHE	LAFTEN	AGO
Trt	%OM	%OM	%OM	%TN	%TN	%TN	Ava. P	Ava. P	Ava. P
T4	6.58	5.67	4.18	0.33	0.28	0.21	10	11	13
T11	6.10	5.39	4.39	0.31	0.27	0.22	12	10	17
T6	5.83	5.65	4.50	0.29	0.28	0.23	15	11	16
T5	6.37	5.76	4.61	0.32	0.29	0.23	14	11	14
T9	6.00	4.99	4.09	0.30	0.25	0.20	13	15	13
T2	6.24	5.64	3.79	0.31	0.28	0.19	13	13	15
T10	6.02	5.37	4.26	0.30	0.27	0.21	11	15	14
T3	6.33	4.97	4.05	0.32	0.25	0.20	14	12	12
T7	5.67	5.42	4.05	0.28	0.27	0.20	18	12	15
T1	5.57	5.68	4.47	0.28	0.28	0.22	12	14	11
T8	6.36	5.84	3.98	0.32	0.29	0.20	13	13	14

Where: %OM (Percent of Organic Carbon), %TN (percent of total nitrogen), Ava. P (Available Phosphorous).

Appendix table **4.** Mean Squares of ANOVA for days to flowing, days to physiological maturity, and number of main branches of soybean at Gobu Sayo district in 2016.

Source of variation	DF	Mean Squares		
		ADF	AMD	NMB
K2O	4	8.011*	3.017	1.520
LIME	1	2.178	1.600	0.484
Location	2	1515.033**	1301.944**	5.123**
K2O * LIME	4	10.178*	4.572*	2.357*
K2O * Location	8	19.936**	9.583**	1.064
LIME * Location	2	13.144*	3.033	0.196
K2O * LIME * Location	8	11.353**	12.256**	0.573
REP	2	0.433	0.878	0.446
Residual	58	2.847	1.200	0.600

*Where: ADF (Days to flowering after sowing), AMD (days to maturity after sowing), (**=highly significant, *=Significant).*

Appendix Table: 5. Mean Square of ANOVA for nodulation parameters of soybean at Gobu Sayo district in 2016.

Source of variation	**DF**	**Mean Squares**			
		NNPP	ENNP	NFW	NDW
K2O		582.166**	538.524**	2.0684**	0.024599**
LIME	1	3309.974**	3750.42**	19.95663**	0.149899**
Location	2	38285.497**	18506.017**	56.2786**	0.149899**
K2O * LIME	4	766.325**	157.204**	1.1872**	0.611438**
K2O * Location	8	2965.967**	351.006**	0.8072**	0.005035**
LIME * Location	2	1889.313**	1138.608**	6.6224**	0.011223**
K2O * LIME * Location	8	1880.981**	186.64**	0.9515**	0.043738**
REP	2	16.005	8.406	0.1753**	0.000802
Residual	58	239.265	4.187	0.1151	0.00104

*Where: NNP (Number of nodules per plant), ENNP (Effective nodule number/plant, NFW (nodule fresh weight), NNDW (Nodule dry weight). (**=highly significant, *=Significant).*

Appendix Table: 6. Mean squares of ANOVA for Root Volume, Nodule volume, and Tap root lengths of soybean at Gobu Sayo district in 2016.

Source of variation	**DF**	**Mean Squares**		
		RV	NV	TRL
K2O	4	10.1235**	10.1235**	3.978
LIME	1	9.9933**	9.9933**	0.204
Location	2	182.46646**	182.4646**	15.615**
K2O * LIME	4	8.4411**	8.4411**	1.889
K2O * Location	8	2.7586**	2.7586**	2.741
LIME * Location	2	2.8602**	2.8602**	0.341
K2O * LIME * Location	8	2.7946**	2.7946**	3.716
REP	2	0.0187	0.0187ns	1.613
Residual	58	0.2806	0.22806	2.011

Where: RV=Root Volume,
NV=Nodule Volume
*TRL= Tap root length, (**=highly significant, *=Significant).*

Appendix Table: 7. Mean squares of ANOVA for Yield and yield related parameters of soybean at Gobu Sayo district in 2016.

Source of variation	**DF**	**Mean Squares**			
		PNPP	PL	NSPD	HSW
K_2O	4	518.88**	0.23085**	0.02611	4.183
LIME	1	642.56**	0.00427	0.00278	22.500**
Location	2	1104.45**	0.71496**	0.17033*	30.833**
K_2O * LIME	4	118.92**	0.04937	0.08944	4.417
K_2O * Location	8	147.80**	0.03423	0.01894	1.583
LIME * Location	2	235.65**	0.11155	0.04811	4.633
K_2O * LIME * Location	8	342.96**	0.10938*	0.04894	6.883**
REP	2	26.07	0.02248	0.03433	2.033
Residual	58	10.17	0.04513	0.05157	1.746

*Where: PNPP=Pod number per plant), PL= Pod length, NSPP= number of seed per pod, HSW=hundred seed weight), (**= highly significant, *=Significant).*

Appendix Table: 8. Mean Squares of ANOVA for yield and yield related parameters of soybean at Gobu Sayo district in 2016.

Source of variation	DF	Mean Squares	
		PH	SBDW
K2O	4	290.32**	28.2704**
LIME	1	914.51**	145.4405**
Location	2	4109.5**	157.8061**
K2O * LIME	4	251.15**	7.2419**
K2O * Location	8	125.04**	16.5300**
LIME * Location	2	43.97**	6.2726*
K2O * LIME * Location	8	182.04**	15.7556**
REP	2	1.90	0.2478
Residual	58	15.01	0.8538

*Where: PH= plant height, (SDBW (Shoot dry biomass weight), (**=highly significant, *=Significant).*

Appendix Table: 9. Mean squares of ANOVA for Harvest index, Biomass yield, and Grain yield per hectare of soybean at Gobu Sayo district in 2016.

Source of variation	DF	Mean Squares		
		HI	BYPH	GYPH
K2O	4	0.008618**	2205450*	1135175**
LIME	1	0.008218*	3755245*	3062147**
Location	2	0.027284**	139494808**	10843969**
K2O * LIME	4	0.006776*	3651625**	121593**
K2O * Location	8	0.004765*	3341400**	219754**
LIME * Location	2	0.010298**	4625905**	1225962**
K2O * LIME * Location	8	0.008206**	4181985**	393384**
REP	2	0.000601	359916	20069
Residual	58	0.00128	575979	13840

Where: BYPH (Biomass yield per hectare), HI (Harvest index), GYPH (grain yield per hectare)

Appendix Table: 10. Monthly weather data summery year 2016

METEOROLOGICAL DATA OF BAKO AGRICULTURAL RESEARCH CENTER

	Rain fall	Air	Temp (oC)		R H	Evapo	Sun shine	Solar radiation	Wind speed (Km/hrs)		Soil Temperature at depth (oC)					
month	(mm)	min	max	ave	(%)	(mm)	(hrs)	(cal/cm2)	1m	2m	0cm	5cm	10cm	20cm	30cn	50cm
Jan	3.2	14.3	31.1	22.7	46.4	---	---	---	0.1	0.33	---	27.2	25.5	23.7	---	---
Feb	2.9	12.7	32.4	22.55	46.2	---	---	---	0.26	0.77	---	27.6	25.4	23.6	---	---
Mar	12.8	14.1	34.4	24.25	45.5	---	---	---	0.51	0.67	---	28.3	25.8	23.8	---	---
Apr	58	14.3	34.6	24.45	46	---	---	---	0.43	0.41	---	27.6	25.8	23.6	---	---
May	220.3	12.8	32.4	22.6	49	---	---	---	0.3	0.56	---	27	27.6	25.7	---	---
June	297.3	14.7	26.5	20.6	52.3	---	---	---	0.23	0.46	---	26.3	26.9	26.1	---	---
July	184.2	14.8	25.5	20.15	56.3	---	---	---	0.21	0.44	---	24.1	25	23.5	---	---
Aug	236.1	14.6	24.8	19.7	56.6	---	---	---	0.2	0.38	---	23.4	23.1	22.7	---	---
Sept	222.8	14.6	26.3	20.45	53	---	---	---	0.17	0.33	---	24.4	24.4	23.6	---	---
Oct	79.1	14.9	28.6	21.75	51.7	---	---	---	0.16	0.24	---	23.5	23.5	23.5	---	---
Nov	0	14.6	29.8	22.2	50	---	---	---	0.13	0.15	---	24.1	24.7	23.8	---	---
Dec	0	10.6	30.1	20.35	49	---	---	---	0.22	0.23	---	24.2	24.7	23.9	---	---
Total	1317	167	356.5	261.8	602	---	---	---	2.92	4.97	---	307.7	302.4	287.5	---	---
mean	x	13.9	29.7	21.8	50.2	x	---	---	0.24	0.38	---	25.6	25.2	24	---	---

Photo taken during data measurement and Evaluation of the Field (Ago site)

`1

Photo taken during evaluation of the experiment by advisors'.

Photo taken during Soybean harvesting.

Photo taken during threshing of the soybean.

Photo taken during seed moisture Vs 100 seed measurement and post-harvest soil sample collection.