Nodulation and Grain Yield of Soybean and Selected Chemical Properties of the Soil as Affected by Liming at Bako Area, Western Ethiopia.

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Abstract
Soil acidity has remarkably been one of the bottlenecks to sustainable agricultural production and productivity that had been prevalent in western part of Oromia with varying degrees of predicament from place to place. *A field experiment was conducted to study the effects of liming on root nodulation and grain yield of soybean and selected chemical properties of the soil at Bako Agricultural Research Center during 2013 main cropping season. There were six treatments comprising five levels of lime and a control with recommended rate of inorganic fertilizer. The experiment was laid out in a randomized complete block design with three replications. Analysis of the results revealed that liming had significant effects on the number of nodules per plant and nodule dry weight per plant, plant height, above ground biomass and grain yield. Application of lime at the rate of* 4.68 *t/ha, which constituted 150% of the recommended rate, was superior to the application of lime at the lower rates in terms of the number and weight of nodules produced per plant. Similarly, grain and biomass yield responses were found to differ under various rates of liming although application of 0.78t/ha lime in excess of the recommended amount resulted the highest improvement. The highest total grain yield of* 4.69*t/ha and above ground biomass weight of 8.27 t/ha were obtained in response to the application of 3.91 t/ha lime which amounted to 125% of the recommended level (i.e.,3.12 t/ha). The yield advantage obtained from liming the soil at this rate over the no-liming (control) was 0.77 t/ha and 1.81 t/ha for grain and biomass yields respectively. With respect to soil chemical properties, it was observed that application of lime brought significant variations in soil pH, exchangeable acidity, Total N, Available P, CEC, exchangeable Ca and exchangeable Mg, Percent Base Saturation and micronutrients. However, it had no significant effect on OC, exchangeable K and exchangeable Na. Comparison of nutrient levels in the soil of the experimental plots before treatment application with post harvesting revealed that liming at every rate increased the soil pH, total N, available P, total exchangeable bases, and base saturation, but decreased the value of exchangeable acidity, organic carbon and the toxic micronutrients compared to the control. Economically the treatment which yields 4.38t/ha is recommended because its' marginal rate of return was 122% followed by the treatment that yields 4.69t/ha having 49% marginal rate of return. In the final analysis, the results indicated that judicious utilization of lime at rates higher than the recommended one enhances the nodulation potential and yield of soybean, improves soil acidity, nutrient availability, and soil productivity overall.*
Keywords: Soil acidity, Element toxicity, *recommended lime Nodulation, yield advantage*

Introduction

A decline in soil fertility implies either decline in the levels of some important soil properties such as soil organic carbon, pH, cation and plant nutrients or increment in the content of certain mineral nutrients levels that are toxic to plants (Foy,1984). In the broadest sense, soil fertility decline includes nutrient depletion and mining (larger removal than addition of nutrients), acidification (decline in pH of the soil beyond the level of tolerance of most crops) and an increase in toxic elements such as aluminium (Al) (Hartemink, 2003)

In western Ethiopia; in some part of West Shewa and in almost all parts of Wellega, soil acidity has remarkably been one of the bottlenecks to sustainable agricultural production and productivity. An inventory of the current surface soil acidity status in this region was carried out in May 2006, as part of the preliminary undertakings of the national acidity reclamation master plan. According to the report of this inventory, most of the soils are strongly (5.1-5.5) to very strongly (4.6-5.0) acidic. However, across all districts, less than 10% of the soils are extremely (4.1-4.5) or moderately (5.6-6.0) acidic (Abdenna *et al.,* 2007).

Such acid-affected soils are usually made more suitable for agricultural use by liming. The maintenance of satisfactory soil fertility level in humid region depends considerably on the judicious use of lime. When soil pH is below 5.5, liming is a common method to increase the soil pH and nutrient solubility and availability and reduce acidity (Anderson *et al*, 2013). Liming enhance the response of crops to organic and inorganic fertilizers and increasing their use efficiency. As most acid soils in Ethiopia are located in areas with adequate rainfall, reclamation of the acidity with application of lime is believed to bring a boost in crop yields. It not only maintains the level of exchangeable Ca and Mg, but it also

Liming acid soil provides a chemical and physical environment for N- fixing bacteria and other soil microbes that encourages the growth and productivity of most common leguminous crop plants which otherwise suffer from strong acidity intolerance. The bacteria (Rhizobia) in nodules on legume roots (soybeans, peanuts, alfalfa, and clover) synthesize greater amounts of nitrogen from the soil atmosphere for use by the legume in places where soil pH is not too low. Treating acid soil with lime enhances nodulation of legumes which improves nitrogen fixation there by raising the reserve or the quantity of the nutrient element in the soil for direct or immediate utilization of the growing legume plant and for residual availability to the succeeding crop. (Crozier and Hardy. 2003).

Soybean is the most nutritionally rich crop as its dry seed contains the highest protein and oil among grain legumes (40 to 42% protein) with a good balance of the essential amino acids. It has 18-20% oil on a dry seed weight basis. It is cheap and rich source of protein for poor farmers, who have less access to animal source protein, because of their low purchasing capacity. It can be used for a variety of purposes including preparation of different kinds of soybean foods, animal feed, soymilk, raw material for the processing industry. Soybean counteracts depletion of plant nutrients such as nitrogen in the soil which results from continuous mono-cropping of cereals, especially maize and sorghum. It is used as a break crop due to its high potential to be intercropped with long stem crops such as maize and sugarcane.

This research is therefore, carried out to investigate the influence of lime amendment on the productivity of soybean with specific objective of examining the effect of liming on root nodulation, growth and yield performance of the crop and some chemical properties of the soil.

Materials and Methods

Description of the study area

The study was conducted at Bako Agricultural Research Centre (BARC) during the 2013/1 main cropping season. The centre is located in the western part of Ethiopia at a distance of 250 km away from Addis Ababa. It lies at latitude of 9^0 6' 00''N and longitude 37^0 9' 00''E and an altitude of 1650 m above sea level. It has a warm humid climate with annual mean minimum and maximum temperatures of 13.5 and 23.7 ^{0}C respectively. The area receives an annual rainfall of 1237 mm from May to October with maximum precipitation in the month of June to August (Metrological station of the centre). The predominant soil type of the area is a strongly structured low activity clayey p fixation Nitisols (FAO-WRB,2014), which is characteristically reddish brown with a pH that falls in the range of very strongly acidic to very acidic according to the rating done by Jones (2003).

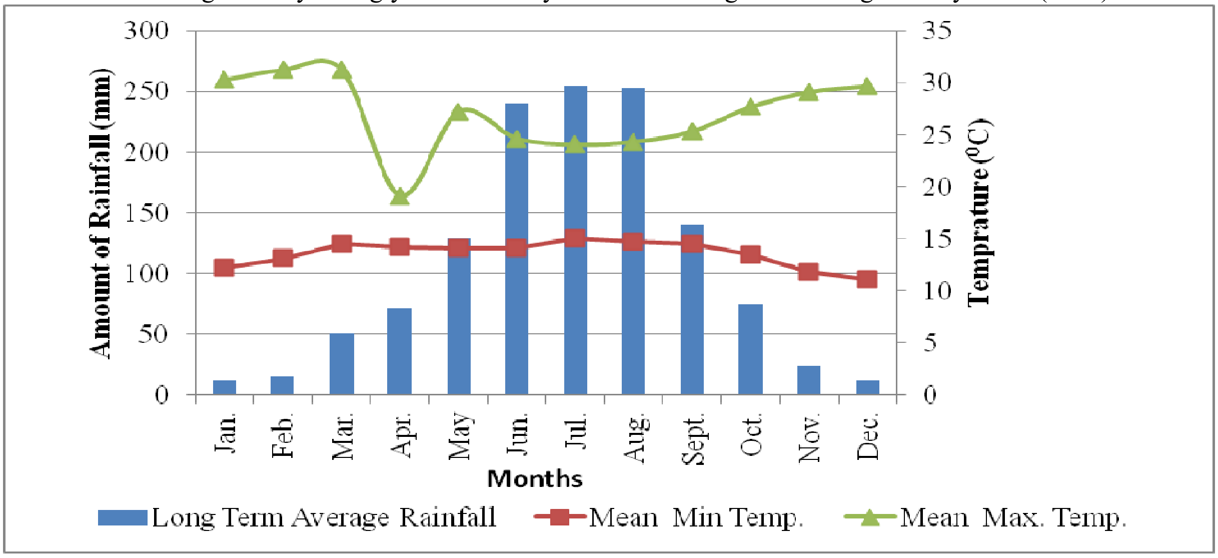

Figure 1. The long term average monthly rainfall and temperature (minimum and maximum) data of Bako Agricultural Research Center (1990-2012)

4.1. Soil properties before the experimental intervention

Laboratory analytical results of selected properties of the soil of experimental site before lime application are presented in Table 1. The results showed that the soil is sandy clay loam in texture and strongly acidic in reaction with exchangeable acidity highly dominated by Al^{+3} with medium organic matter and total nitrogen content, according to the rating done by Landon (1991) . The Bray available P level of the soil is very low according to Jones (2003) and is below the critical level (Tekalign, 1991) According to Hazelton and Murphy (2007) the experimental soil has moderate CEC and high base saturation, low exchangeable Ca, moderate exchangeable Mg, medium exchangeable K and very low exchangeable Na.

The classification limit set by Dinkins (2007) shows that the soil is low in soil available P, while the rating by Peter, Bierman and Eliason ranked the value to medium. The low P content of the soil is probably attributed to high P fixing capacity of the soil at Bako (Girma, 2001; Wakene *et al*., 2002)..With regard to content of micronutrients in the soil of the experimental field, Mn and Fe are found in high and very high content respectively. Cu is medium while Zn is available in very low Concentration (Peaceful Valley farm supply technical booklet, 2004). This implies that there is an excess amount of Fe and Mn beyond the preferred level for plant growth in the soil but adequate and scarce amount of Cu and Zn respectively. These and the aforementioned chemical properties of the soil coupled with its high level of exchangeable acidity indicate that the fertility status of the experimental soil is lower and the nutrient level is inadequate for successful crop production. Hence conditioning the soil by liming to reduce the toxic effect of acidity and to increase nutrient availability and, minimize their external application to maintain its health fertility and productivity is immense

Table1. Selected physical and chemical properties of the of experimental soil before planting

No Parameters	Test Result (value)
Sand (%)	45.28
Clay (%)	38.36
Silt (%)	16.36
Textural Class	Sandy clay loam
pH-H_2O (1:25)	5.13
Exchangeable acidity (Cmol(+)/kg soil)	1.29
Exchangeable Aluminum (Cmol(+)/kg soil)	1.03
Organic carbon (%)	2.58
Total nitrogen (%)	0.13
C:N ratio	17.6
Available phosphorus (mg/kg soil)	5.67
Exchangeable calcium (Cmol(+)/kg soil)	4.50
Exchangeable magnesium (cmol(+)/kg soil)	2.26
Exchangeable potassium (cmol(+)/kg soil)	0.50
Exchangeable sodium (cmol(+)/kg soil)	0.05
Total Exchangeable Bases (cmol(+)/kg soil)	7.32
Percent base saturation (PBS)	36.9
CEC (cmol(+)/kg soil)	19.70
Manganese (mg/kg soil)	42.05
Iron (mg/kg soil)	33.00
Copper (mg/kg soil)	1.48
Zinc (mg/kg soil)	0.89

CEC – Cation Exchange Capacity

Experimental materials

Liming

The liming material used in the experiment was ground dolomitic limestone of standard particle size (fine enough to pass a U.S. Standard No. 8 sieve) and CCE (Calcium Carbonate Equivalent) of 90% confirmed by laboratory test.

Planting

The test crop used in the experiment is a soybean variety locally called Jalelle, which was released by Bako Agricultural Research Centre in the year 2003. The variety has white and yellow flower and seed color with wide elliptic leaf shape and indeterminate growth habit. It is adapted to an altitude range of 1300-1850 meter above sea level with rainfall of 900-1300 mm in growing season. The variety is tolerant to important diseases like bacterial blight and bacterial postule

Soil sampling and analysis

Ten sub samples were collected from uniform area using a zigzag pattern to make a representative composite soil sample using a cylindrical auger from a surface layer of 20cm from the whole experimental field before liming, and from each treatment plot in the individual blocks after harvesting (Darrryl, 2000). The collected soil samples were air-dried, ground and sieved using a 2 mm size sieve for clayey soils and 0.5 mm size sieves for soils with a high percentage of sand or organic material to achieve sample homogeneity for determination of Exchangeable acidity, Organic carbon, Total nitrogen and micronutrients (US Davis Analytical Lab, 2014). The prepared soil samples were analysed to determine the rate of liming required before planting, to determine the major soil chemical properties before and after treatment application (after harvest) following the standard laboratory

procedures. The recommended rate was computed from the threshold value of exchangeable acidity of the soil of the experimental field and the permissible acid saturation of the crop assuming that1cmol/kg soil of soil acidity can be neutralized by applying 3 tonnes of lime per hectare (Taye, 2001).according to the equation
LR = LRF (EA – PAS). Where, LRF = Lime Requirement Factor, PAS=Permissible Acid Saturation, EA= Exchangeable Acidity

Treatments and experimental design
The experiment consisted of six levels of lime (0, 1.56, 2.34, 3.12, 3.9, and 4.68 t/ha) which was laid out in randomized complete block design (RCBD) with three replications. A gross plot size of 4 m x 4 m = (16 m2) was used with a spacing of 1m and 2m b/n plots and blocks respectively.

Experimental procedure
Lime was applied by spreading on a well-ploughed and pulverized seed bed incorporating it into the soil plough depth two months prior to planting. At planting, the soybean seeds were sown at intra and inter spacing of 10 and 40 cm respectively, at mid of June along with the recommended rate of fertilizer (60 kg ha^{-1} DAP), which was band applied. The seeds was dribbled at the prescribed spacing to a shallow depth of about 5 cm and covered with the soil Subsequent agronomic activities following the emergence of the seedlings such as weeding, harvesting, and threshing was performed according to the locally adopted methods

Crop data collection and procedures
When the plants reached early stage of pod formation or mid-flowering stage, five plants were randomly selected from the middle rows for data collection on root nodulation. The whole harvestable rows were used for collecting data on grain yield at harvesting in which the uprooted number of plant samples used for estimation of nodulation and biological yield were considered in the stand count. The effective nodules were_identified and their mean count obtained from five randomly selected plants were recorded as number of nodules per plant. The average weight of effective nodules of five plants dried at 70 ^{0}C for 24 hours was taken as nodule dry weight per plant, whereas the average nodule volume of five plant samples measured by displacement of water using a graduated measuring cylinder was taken as nodule volume per plant.

The plant stand count was recorded at the time of maturity just before harvesting from the harvestable rows of each experimental plot. The height of ten randomly selected plants were measured from the ground to top of the plant and the means were recorded as plant height (cm) at flowering. The above ground dry biomass was measured near physiological maturity stage before leaf biomass is shattered at harvesting from 10 randomly selected plants. Total biological yield per plot area was calculated from the harvestable rows based on biomass of the sampled plants. Grain yield was recorded from each net plot area where the moisture is adjusted to standard moisture content of 10% as designated for pulse crops according to the guidelines by Biru Abebe (1979)

Statistical analysis
The collected data were subjected to analysis of variance using the General Linear Model of SAS (SAS, Inst, Carry, 2000). Treatment means were separated using the Least Significance difference test at 5% significant level.

Economic Analysis
To consolidate the statistical analysis of the agronomic data, economic analysis was done for each treatment. For economic evaluation, crop yield, adjusted crop yield, costs that varies and filed price of crop produce were considered and gross field and net benefits were calculated according to the procedure given by CIMMYT (1998). Marginal rate of returns for each treatment were also calculated by having control treatment as bases for all treatment. To estimate economic parameters, soybean price was valued at an average field price and transportation cost of lime was considered while its price was not considered because lime was for free at that time.

Results and Discussion
Growth parameters
Nodulation potential
1.2.1 Nodule number
Analysis of variance indicated a significant ($P < 0.01$) variation in number of effective nodules per plant due to different levels of liming (Table 2). The average number and volume of nodules per plant increased progressively with incremental application of lime up to 4.68 t/ha.

The results indicated that the highest number of nodules per plant (113) was obtained from the experimental unit that received the highest dose of lime, which has improved the number of nodules by 73.84% as compared to the control. The difference in number of nodules among the treatments might be due to the effects of variation in lime rates in suppressing the severity of acidity. Liming might have provided better soil environment for nitrogenous activity, improved biological activities, and a relatively enhanced supply of essential nutrients to the crops that enhanced the nodulation potential and multiplication of effective rhizobium. The differences in concentrations of calcium between the liming rates might have also resulted in different nodule number per plant, as Calcium has of paramount importance in nodule formation in the soil. This is in agreement with the findings of Kisinyo *et al.(2005)* who found sole or combined application of lime and P had significant effects on nodule number and volume, whereas there was little nodulation without lime even with the highest P rate applied, indicating that soil acidity is a limitation to rhizobial activity.

1.2.2. Nodule dry weight

Application of increased lime rates has also influenced the nodules dry weight per plant considerably showing significant differences (P≤0.05) among the lime levels. The results revealed that maximum nodule dry weight (963.3 mg/plant) was obtained from plots that received 4.68 tons/ha which was significantly higher than that of the other lime treatments (table 2). As compared to the control, a considerable increment of 71% nodule dry weight was recorded when 150% of the recommended(4.68 t/ha) lime was applied. This is in line with the finding by Suryantini,(2013) who reported that the increase in soil pH resulting from the application of lime provides a more favorable environment for soil microbiological activity for increased nodulation and grain yield of soybean

The increased nodulation and nodule mass of soybean due to lime application could be attributed to favorable conditions created by higher soil pH values, which may have created a better medium that fosters the proliferation of indigenous soybean nodulating bacteria existing in that soil. On the other hand, low rhizobium numbers and inhibition of nodule initiation might have been responsible for the lesser nodule weight in the control treatment.

Table 2. Effect of liming on Nodulation and plant height of soybean

Treatment No.	Lime rate (t/ ha)	Nodule Number/plant	Nodule Volume/plant (ml	Nodule Dry wt./plant (mg)	Plant ht.(cm)
1	0	65d	2.16	563.33d	45.93c
2	1.56	84c	3.76	633.33dc	50.93b
3	2.34	85c	4.30	650.00bc	55.26b
4	3.12	93bc	4.43	653.33bc	53.50b
5	3.90	97b	2.93	713.33b	51.66b
6	4.68	113a	3.26	963.33a	60.23a
	LSD	11.185	NS	79.69	4.36

LSD (0.05) - Least Significance Difference at 5% of Probability level, NS – Non-significant at P≤0.05. Means within a column followed by the same letter (s) or with no letter are not significantly different at P≤0.05

1.3. Plant height

Plant height was significantly influenced (P≤0.01) due to liming . An increasing trend in plant height was observed with increasing liming rate, whereby the highest plant height with 31.1% increment over the control was obtained from the plot that received the highest lime rate (4.68 t/ha). This might be due to the improvement of soil condition by liming wherein growth promoting nutrients such as nitrogen would be adequately supplied through fixation. Additionally, the improvement in soil condition will also positively influence other biological processes that enhance utilization of carbohydrates in the formation of protoplasm and thereby promotion of cell division and elongation to obtain higher plant height, and number of leaves and branches. This finding is in line with the observation of Werkineh *et al*. (2013) who reported that application of lime and nitrogen fertilizer separately as well as in combination gave significantly higher number of pod bearing branches; shoot dry weight and taller soybeans than those crops grown without lime and nitrogen when soybean was grown without inoculation

Yield and related attributes

Stand count

The analysis of variance showed that liming had no significant effect on stand count at harvest; however, liming at every rate improved the germination and establishment of soybean than no liming (Table 3)..

Biomass yield

A significantly higher value of above ground biomass was obtained from plot that received 3.90 t/ha of lime, and all other lime treatments resulted in significantly higher biomass weight than control (Table 3). Application of lime at the rate of 3.9 t/ha improved the above ground biomass by 19.6% compared to the control. The possible reason for the substantial increase of biological yield through liming could be attributed to the better nodule development, which stimulated effective N_2 fixation, increasing the amount of N available to the plant to support growth. Another reason could be the suppressing effect of lime on Al concentration and acidity so that inhibition of root growth due to Al toxicity is counteracted. Reduction in soil acidity due to liming will also enhance solubility, availability and uptake of nutrients, and hence improved growth of the soybean is realized. This is in agreement with result of Wietske (2012) who found a significant increment in average shoot dry weight of the soybean plants through application of lime. The author discussed that the positive effects of lime on production and biomass yield are usually caused by several factors including: reduced levels of Al^{3+} and Mn^{2+}, which minimize their negative impacts on the rhizobia $^{+}$, an increase in N_2 fixation, extra supply of Ca and an improved availability of nutrients.

Grain yield

The result of this study revealed that all lime treatments were significantly different from the control in terms of grain yield. Liming at the rate of 3.9 t/ ha gave a significantly higher grain yield of soybean than the control and other lime levels (Table 3). Mean grain yield at this rate was higher than that of control by 19.64%. The significant response in seed yield obtained from this rate and the other lime treatments could be due to the increment of soil pH and decrease of exchangeable acidity (Table 4) that might have enhanced nodulation and biological nitrogen fixation to improve the nitrogen economy of the soil, nutrient availability and solubility. This improvement in soil condition and nutrient availability will intern facilitate the uptake of the nutrients by the plant. Additionally, the Ca and Mg contained in lime will also be supplement to the soil reserve. Similar positive effects of liming on soybean yields were also reported by Kovacevic *et al*. (2011), who obtained soybean yield increase by 18% through application of 10 t/ ha of granulated dolomitic lime. Comparable investigation on soybean by Vongvilay *et al.* (2009) illustrated that liming had beneficial effects on soybean where yield of soybean was improved by 50.8% compared with the control.

Table 3.Influence of liming on Grain Yield and biomass weight

Treatment No.	Lime rate (t/ha)	SC/plot	Biomass (t/ha)	Grain yield (t/ha)	HI
1	0	540	6.46c	3.92c	0.61
2	1.56	604	7.3b	4.38ab	0.60
3	2.34	617	7.66ab	4.36ab	0.57
4	3.12	564	7.46b	4.20cb	0.56
5	3.90	593.	8.27a	4.69a	0.57
6	4.68	605	7.57ab	4.14cb	0.55
	LSD	NS	0.74	0.41	NS

LSD (0.05) - Least Significance Difference at 5% of Probability level, SC- stand count, and HI-Harvest Index. Means within a column followed by the same letter (s) or with no letter are not significantly different, NS - Non-significant at $P \leq 0.05$

Post-harvest soil properties

Application of lime at all rates increased the soil pH, available P, total nitrogen, total exchangeable bases, base saturation, but decreased the value of exchangeable acidity, organic carbon, toxic micronutrients and CEC as compared to the control during the plant growth (Table 4,5 and 6).

Soil pH and Exchangeable Acidity

The soil pH increased with increasing rates of lime from very acidic (5.11) to slightly acidic (5.95) range (Jaka *et al*., 1994), although the increment over the control was not pronounced (Table 4). The increase in pH results from neutralization of H^+ in solution by the supply of either HCO_3 - or OH^-, from the liming material (Tisdale *et al.*, 1993). The high annual rainfall (1237 mm) in the study area is responsible for leaching of base forming cations to change the soil from strongly acidic to slightly acidic pH range. The is concordant with the finding of Luka *et al.* (2012) who reported that soil pH increased from 4.75 to 5.28 and close to neutral after application of 3 and 5 t /ha of lime, respectively.

The lack of strong effect of liming on pH in this study might have been due to the short duration for the lime to dissociate and disperse in the soil medium to suppress the activity of the hydrogen ion in the soil solution. Wortmann *et al*. (2005) reported that it could take up to two years for the full effect of lime application to be effective. Furthermore, study conducted on oat and soybean in southern Brazil on Oxisols with clay contents between 220 and 620 g kg^{-1} have shown that the maximum lime reaction in the soil surface layer occurs up to 2.5 or 3 years after surface liming where higher reaction of the neutralizing agent was obtained when compared with 1 year after surface lime application (Oliveira & Pavan, 1996; Caires *et al*., 2008).

Table 4. Soil acidity status after harvesting

Treatment No.	Lime (t/ ha)	pH-H_2O(1:2.5)	Ex. Acidity (cmol/kg soil)
1	0	5.11d	0.71a
2	1.56	5.35c	0.48ab
3	2.34	5.46cb	0.21c
4	3.12	5.68ab	0.29cb
5	3.90	5.87ab	0.27cb
6	4.68	5.95a	0.19c
	LSD	0.2	0.24

LSD (0.05) - Least Significance Difference at 5% of Probability level
Means within a column followed by the same letter (s) are not significantly different

Mean square of ANOVA **for** soil acidity measures: pH-H_2O (active acidity) and exchangeable acidity showed that both were affected significantly ($P \leq 0.01$) by liming (Table 4). Generally, there was a remarkable decrease in soil exchangeable acidity with increasing liming rate whereby the value decreased significantly by more than 200%. This could be attributed to the increase of soil pH and decrease of Al concentration to sub-toxic levels by the reaction with lime in the soil. The result of the study is in conformity with the finding of Opala (2011) which illustrated that the reduction in exchangeable acidity and exchangeable Al that can partially be attributed to increase in soil pH that was observed when lime was applied to the soil. Several other authors have measured an increase in soil pH with concomitant decrease in exchangeable acidity during lime reaction in soils (Narambuye and Hynes 2006 and Tang *et al.*, 2007). An increase in soil pH results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides (Ritchie, 1994**)** thus reducing concentration of Al in soil solution. The finding of Adane (2014) also indicated soil pH increased with increasing limestone application, while exchangeable acidity of the soil was significantly ($P \leq 0.01$) decreased with all increasing rates of lime

Soil organic carbon, Total Nitrogen and Available Phosphorus

The average organic carbon content of the soil kept decreasing with increasing levels lime application, except at 3.125 t/ha. This decrease in organic carbon content indicates that liming promotes rapid breakdown of organic reserves in the soil, releasing nutrients for growing plants. Monroe and Lloyd (1993) also reported that addition of lime increased microbial activity and the degradation of organic matters in the soil by 50%, from 3.2 to 4.7 mg g^{-1}, as determined by CO_2 evolution.

Table 5. Organic Carbon and Total nitrogen content after Harvest

Lime rate (t /ha)	Organic Carbon (%)	Total Nitrogen (%)	C :N	Av.Phosphorus (ppm)
0	2.61	0.14cb	18.64a	5.67c
1.56	2.26	0.18b	12.55b	6.87c
2.34	2.26	0.18b	12.55b	8.28ab
3.12	2.50	0.19b	13.15ab	7.23abc
3.9	2.25	0.23ab	9.78c	7.90ab
4.68	2.40	0.26a	9.23c	8.74a
LSD	NS	0.11	2.69	1.77

LSD (0.05) - Least Significance Difference at 5% of Probability level
Means within a column followed by the same letter (s) are not significantly different

Unlike OC, the total nitrogen concentration in the soil increased with increasing rate of lime supply (Table 5). The total N content of the experimental soil (0.13%) remained unchanged in the control plot (0.14%) while the value increased by 100% at the highest lime rate (Table 5).Addition of lime increased soil pH conditioning the environment for microbes and this might have accelerated the process of decomposition of organic matter in which, organic nitrogen is converted to inorganic ammonium and released into the soil in available form, though the net increase of total Nitrogen in the soil was possibly attained through biological fixation of atmospheric nitrogen rather than mineralization. Similarly, Ranjit (2006) reported that application of lime within the range of 3-5 tons/ha recorded higher total nitrogen than other levels of lime

The carbon to nitrogen ratio(CN) was influenced significantly ($P \leq 0.05$) in similar manner as total N by liming in which application of higher lime levels recorded significantly lower value of CN compared to the control, a value which is found in ideally suitable range for the growth of most agricultural crops

The lower soil C:N ratios could intern influence microbial nitrogen use efficiency and nitrogen dynamics, favoring faster organic matter decomposition and nitrogen mineralization by microorganisms in limed soils (Mooshammer et al., 2014). Similar results were also reported by Doddamani (1975) and Patil and Ananthanara (1989) that when acid soils were limed, C:N ratios between liming rates revealed statistically significant ($P \leq 0.05$) differences.

Ameliorating the soil with lime resulted in significant increase in available P. For instance, application of the highest rate (4.68 t/ha) increased the available P content of the soil by 54.14% over the control (Table 5). The increment could be due to the neutralization of soil acidity and the resultant decrease of free Al and Fe contents which fix the available P in the soil. This fact is more emphasized in Kisiniyo's report which stated that liming increased soil pH and P availability, where the Ca^{2+} and Mg^{2+} in lime displace Al^{3+}, Fe^{2+} and H^{+} ions from the soil sorption sites resulting in reduction of soil acidity and P fixation.

CEC, Exchangeable Bases and Percent Base Saturation (PBS).

Mean square of ANOVA **for** the cation exchange capacity (CEC) of the soil showed a significant variation ($p<0.05$) among the experimental units with liming (Table 6). The average value of CEC increased with increasing rate of lime probably due to the increment of soil pH owing to neutralization of soil acidity by the action of lime. This finding is in accordance with the observation of Turner and Clark (1966) who reported that liming soils to higher than pH 5 maintain exchangeable plant nutrient cations, showing the interdependency of soil pH and CEC; degree to which a given amount of lime per unit of soil volume will increase Cation Exchange Capacity (CEC) depends on the pH. This is in agreement with the finding of Adane(2014) who stated that the increase in CEC due to liming could be attributed to the change in pH and the release of the initially blocked is amorphous and interlayer substitution of negative charge by de-protonation of the variable charge minerals and functional groups of humic compounds caused by Ca^{2+}.

Total exchangeable bases showed a significant ($p<0.01$) variation due to liming. Among the individual exchangeable cations, Ca and Mg were influenced significantly ($p<0.05$) and highly significantly ($p<0.01$), respectively, whereas K and Na were not affected by lime amendments. The values of exchangeable Ca and Mg increased by 40 and 96.5% due to application of 4.68 and 3.9 t/ha lime, respectively. On the other hand, the exchangeable K content of the control plot was higher than that of all limed plots, probably due to the antagonistic effect of calcium concentration on potassium in the soil,where the divalent cation(Ca) is more favored for the ionic substitution in the silicate interlayers due to its higher charge density and conversely, it is hard for the monovalent potassium ion to replace the trivalent aluminium ion in the soil complex (Athanase et al 2013). Virtually all of the newly created pH dependent exchange sites are taken up by Ca, which is not surprising as Ca is the major cation present in the limestone used, coupled with the selectivity for Ca, causes K to be displaced from the exchange complex. These observations are also consistent with the finding of Edmeades (1992) who noted that possible explanation for these decreases in exchangeable K is that liming increases the amounts of this nutrient lost by leaching; the addition of large amounts of Ca, in excess of the amount taken up in the newly created exchange sites, coupled with the selectivity for Ca, causes Mg and K to be displaced from the exchange complex, thus increasing the potential for loss by leaching.

The percent base saturation followed the same trend as the total exchangeable base, the analysis of variance showing a highly significant ($p<0.01$) variation due to liming, in which the highest value (51.86%) was obtained from the plot that received 4.68 t/h of lime. This result is in accordance with observation of Hayens (1981) who summarized that liming resulted in an increase of exchangeable Ca and thus in percentage base saturation, with concomitant decreases in levels of exchangeable Al, Fe and Mn.

Table 6.Effect of liming on Exchangeable Cations and related soil properties.

lime rate (t /ha)	Ex. Na (Cmol)/kg	Ex.K (Cmol)/kg	Ex.Ca (Cmol)/kg	Ex.Mg (Cmol)/kg	T.Ex.B (Cmol)/kg	CEC (Cmol)/kg	PBS
0	0.05	0.50	3.50bc	2.26d	6.32c	15.65c	40.38d
1.56	0.06	0.34	3.94b	3.43c	7.77b	16.77bc	46.33cd
2.34	0.07	0.37	4.05b	4.29b	8.78ab	17.4b	50.49b
3.12	0.06	0.34	3.95b	4.44b	8.8ab	18.49a	47.59c
3.90	0.057	0.42	3.83bc	5.07a	9.49ab	18.53a	51.21ab
4.68	0.056	0.34	4.90a	4.44b	9.74a	18.78a	51.86a
LSD	NS	NS	0.81	0.49	1.01	1.03	2.76

LSD (0.05) - Least Significance Difference at 5% of Probability level. PBS - Percent Base Saturation
Means within a column followed by the same letter (s) are not significantly different

Soil Micronutrients

The manganese content of the soils decreased very significantly ($p<0.01$) due to progress in the rates of liming except the first two lower levels which didn't conform to this trend. Similarly the iron content had also kept decreasing against the increasing level of lime even if the decline is not significant. A significant reduction of 26%% manganase content was observed due to liming the soil at recommended rate. as compared to the control. The other micronutrients didn't responded soundly to the variation of lime level. which could be due to lack of pronounced increase of soil pH as availability of most micronutrients is largely pH dependent. The response of Mn and Fe to slight change in pH caused by liming could probably be due to an excess amount of Fe and Mn beyond the preferred level for plant growth in the soil (Table 1). This is similar to the one observed earlier by Takáč et al. 2009, where zinc and copper contents changed less, while the amount of DTPA extractable forms of iron and manganese resulted in a strong decrease due to liming. This could be substantially supported by the fact that lime application neutralizes soil acidity, raises soil pH where, increasing the pH of an acid soil decreases the availability of Micronutrients like Manganese and iron (Monroe et al, 2005).The result of this study is also in conformity with the finding of Bertic *et al.* (1988) who assessed the influence of liming on manganese and iron availability in acid soil of East Croatia, Yugoslavia. Due to application of the highest rate of lime, Mn and Fe content in the soil decreased from 45 and 34.1 mg/kg (un-limed plot) to 29 and 14.1 mg/kg (limed plot) respectively.

Table 7. Soil micronutrients after harvest as influenced by liming rates.

Lime rate (tha^{-1})	Micronutrients (mg/ kg)			
	Mn	Fe	Cu	Zn
0	42.05a	32.08	1.50ab	0.92ab
1.56	37.69b	31.56	1.54ab	0.93ab
2.34	35.18bc	31.93	1.61a	0.95ab
3.12	31.11c	29.48	1.51ab	0.94ab
3.9	32.33c	28.80	1.44b	1.03a
4.68	33.94bc	29.87	1.53ab	0.78b
LSD (0.05)	4.24	NS	0.13	0.24

LSD (0.05) - Least Significance Difference at 5% of Probability level. Values followed by different letters in the column or row of mean are significantly different from each other at P<0.05.

Economic Analysis/Partial Budget Analysis

Different literatures argue that farmers' goals and constraints of production determines different recommendations that farmers will use, researchers must be aware of the human element in farming, as well as the biological element. In the first place, many farmers are primarily concerned with assuring an adequate food supply for their families and secondly, whether farmers market little or most of their produce, they are interested in the economic, will consider the costs of changing from one practice to another and the economic benefits resulting from that change (CIMMYT, 1988). The research was carried out to investigate the influence of lime amendment on the productivity of soybean as soil acidity is among major problem in western part of the country that shrinks the productivity of crop production. This research activity do have six treatments of which all of them varies at least in their cost of lime transportation and cost of labor used for lime application to the farm land. Therefore; the need for economic analysis arises for this research as farmers are sensitive to costs that are changing from one practices to another resulting in to different levels of benefits. This partial budget analysis; is therefore, to identify the most economically feasible treatments among the others.

Table 8. Partial budget analysis of treatments

Partial budget analysis						
	Treatments					
	1	2	3	4	5	6
Average yield	39.2	43.8	43.6	42.0	46.9	41.4
Adjusted yield	35.28	39.42	39.24	37.80	42.21	37.26
Gross field benefits (Birr/Ha)	31,752	35,478	35,316	34,020	37,989	33,534
Cost of lime transportation (**Birr/ha)**	0.00	1,404	2,106	2,808	3,510	4,212
Cost of labor for lime application	0.00	273	409.5	546	682.5	819
Total cost that vary **(Birr/ha)**	0.00	1677	2515.5	3354	4192	5,031
Net benefit	31,752	33,801	32,800	30,666	33,796	28,503

Source: computed from own data

This partial budget analysis shows that costs that vary among treatments were cost of lime transportation from where it was brought and costs of labor for lime application to the farm land. During the time of this research activity implementation lime was obtained freely without any cost. Regarding the net benefits obtained from each treatment, the table above show that treatment number two is the first followed by treatment number five and treatment number six gives less benefit than the one without lime application/controlled treatment.

The benefit curve of the treatments shows increments in net benefits from controlled treatment to treatment number three but less than controlled treatment benefit was observed at treatment number four. Treatment number five gives the second largest net benefit net to treatment number two while treatment number six gives the list and even less than treatment number four and the controlled treatment benefits.

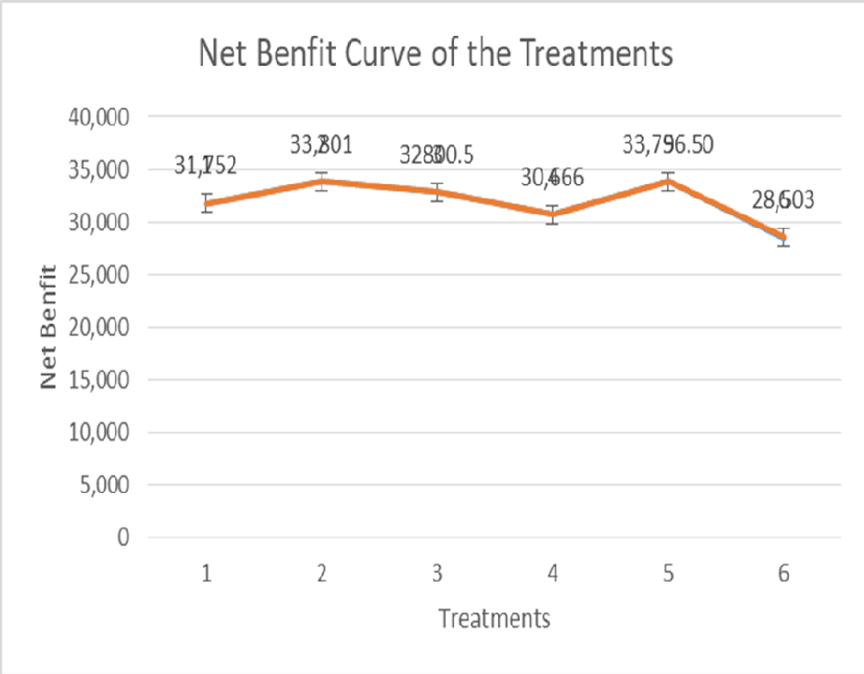

Figure 2. Net benefit curve of treatment

Marginal Rate of Returns of the Treatments

The marginal rate of return indicates what farmers can expect to gain, that is on the average, in return for their investment when they decide to change from one practice (or set of practices) to another (CIMMYT, 1988). In our case where we were dealt with the experiment on chemical properties of the soil as affected by liming, adopting the second experiment rather than not liming implies that a 122% rate of return, in a similar manner adopting treatment number three and five results in 42% and 49& rate of return. However, adopting treatment number four and six results in negative rate of returns where investment in liming is not recommended economically. As the analysis shows treatment number one, five and three are recommendable economically respectively as their investment turn over shows positive.

Nevertheless, a decision cannot be taken regarding such type of treatments by considering their economic benefits; marginal rate of return, because this marginal rate of return is calculated from one year data however, the effect of liming on soil fertility improvement will go beyond one year that intern will decrease the cost that farmers going to incur to purchase fertilizers for crop production. Therefore; without considering the long term benefits of lime application that improves soil fertility and without knowing what rate of return is acceptable to the farmers it is difficult to decide the lowest acceptable marginal rate of return on such type treatments.

Table 9. Marginal rate of return of treatments with respect to the control treatment

Cases	Marginal rate of return
1. From treatment one to treatment two	122
2. From treatment one to treatment three	42
3. From treatment one to treatment four	-32
4. From treatment one to treatment five	49
5. From treatment one to treatment sixe	-65

Source: own data

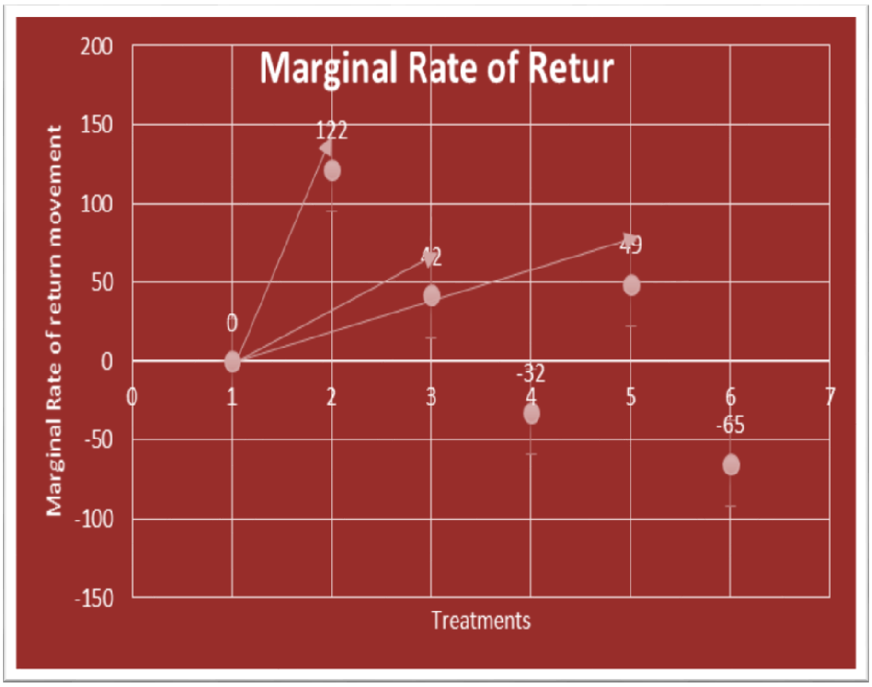

Figure 3. Marginal rate of treatments with respect to control treatment

Sensitivity Analysis

In this globalized and interdependent world markets fluctuates, inflation is common phenomenon, and policies are often changing and unpredictable enough that there is no way for researchers to predict prices of inputs and outputs with any certainty even for a few years in the future. Therefore; recommendations that will be able to withstand any changes in prices of inputs or crops for at least a few years should have to be made for the sustainability of investment on such type of treatments. Sensitivity analysis of such treatments is the best way to test a recommendation for its ability to withstand such price changes in inputs or crops output.

Sensitivity analysis simply implies redoing a marginal analysis with alternative prices of inputs and crop produce. Most commonly, sensitivity analysis is done by increasing the price of inputs, keeping the other variables or by decreasing the field prices of crop produce. In our case the price of lime was not yet established and the treatments were meant for acidity reclamation that in turn results in long term improvement of soil fertility. This long term soil improvement befits farmers in decreasing the costs of fertilizers input in the coming cropping seasons that cannot be handled under this sensitivity analysis. Therefore; the treatment with high marginal rate of return could be recommended economically but it needs further investigation for such further prices changing scenarios.

Conclusion and recommendation

The result of this study revealed that the optimum values for majority of agronomic traits and soil properties considered in the experiment were obtained from application of lime at the recommended and above the recommended rate. Hence, ameliorating the acidity of soils within the range similar to that of the experimental site through applying lime at higher rates than the recommended one is better than using the minimum dose to neutralize acidity, replenish soil fertility, and enhance crop productivity.

By virtue of its current dimension and magnitude in Ethiopia, soil acidity should be given a top priority as one of the problems hindering agricultural productivity worth tackling. It is the view of the author that the tendency of the problem to be a threat to the productivity of the sector in the future is potentially high if it is not counteracted. The saying of one scholar which goes 'Soil acidity is a hibernating monster' perfectly fit to the Ethiopian condition and can be considered as the right definition reflecting the nature of the problem. This should alert every concerned agricultural personnel and governmental sectors in the line, who had been following a 'touch and release' trend in handling the situation, to reconsider the case to come up with a well-designed and organized strategy towards combating this problem sustainably.

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