Influence of Liming to Alleviate Soil Acidity and Phosphorus Fixation through Amelioration of Soil Nutrient Availability

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Abstract
Nutrient availability and phosphorus fixation is one of the crop yield limiting factors in acidic Soil of western Ethiopia. Thus, a field experiment was carried out in 2014 main cropping season from the end of June to end November at Haro Sabu to assess the influence of lime and phosphorus rates on the yield of groundnut. The treatments were factorial combination of five rates of phosphorus (0, 11.5, 23, 46, 57.5 kg P2O5) and four rates of lime (CaCO3) (0, 2.25, 3 and 3.75 tons ha-1) in randomized complete block design and replicated three times. The pre soil analysis indicated that the soil of experimental area was acidic (pH = 5.31) and low in available P (2.34 mg kg-1). The soil textural class was sandy clay loam with constituents of sand (53%), clay (19%) and silt (28%). Application of both lime and phosphorus to the Experimental plot increased exchangeable Ca, available phosphorus and total nitrogen while decreased exchangeable aluminum. The main effect of phosphorus and lime showed a significant effect on seed yield. Increasing phosphorus rate increased dry pod yield and seed yield linearly up to 23 kg P2O5 ha-1 while increasing lime rate to the level of 3 tons ha-1increased shelling percentage and seed yield to maximum level but further addition of lime supply high dry pod yield at the rate of 3.75 tons lime ha-1.

INTRODUCTION

Soil acidity has become a serious threat to crop production in most highlands of Ethiopia in general and in the south, south western and western part of the country in particular. About 41% of potential arable land of Ethiopia is acidic (Workneh, 2013). Currently, it is estimated that about 67% of the total arable land of Wollega is affected by soil acidity (Abdenna et al., 2007). The production of groundnut under acidic conditions is low due to calcium and magnesium supply is reduced and plant growth suffers. Moreover, other beneficial nutrients are in deficient concentration in soil solution (Ranjit, 2005). Groundnut commonly responds to Ca additions under acid soil conditions, due to the fact that Ca is required for adequate pod filling. In acid soils, availability of certain nutrients like aluminum, iron and manganese increases due to higher dissolution and at times becomes toxic. In strongly acidic conditions, phosphorus reacts with active iron and aluminum (Al) forming insoluble phosphates. When the pH falls below 6.0, the availability of nutrients such as phosphorus, potassium, calcium, and magnesium decreases. The main purpose of lime in dealing with soil acidity particularly on legume is due to its effect on improving crop responses to fertilizers by improving nutrient availability and uptake especially phosphorus, reducing aluminum(Al) toxicity and promoting the activities of such desirable organisms as rhizobia bacteria which fix nitrogen for legumes (Nekesa, 2007). In western parts of the country, the farmers shifted their land to produce relatively acid tolerant crops such as maize, and in some parts they left their land as a fallow for two to four years without any cultivation hence even in some parts the land left only for grazing (Abdenna et al., 2007). In addition, no work has been done especially in the western part of the country to evaluate the effect of phosphorus and lime application on groundnut.

MATERIALS AND METHODS

Description of the soil of Study Area

The composite soil analysis done before planting at Nekemte soil libratory indicated that the soil type of the experimental site is reddish brown in color with soil textural class of sandy loam. The soil has a pH of 5.31 which is acidic, available phosphorus 2.34 mg kg-1 rated as low, total nitrogen of 0.275% rated as medium, Exchangeable Ca2+ (5.379 cmolc kg-1) rated as medium according to the rating of Landon (1991) and Exchangeable acidity (Al3+) of 1.4 cmolc kg-1 rated as very high according to Moore (2001) (Table 1).

Treatments and Experimental Design

The treatments consisted of five rates of phosphorus (0, 11.5, 23, 46, 57.5 kg P2O5) and four rates of lime (0, 2.25, 3 and 3.75 tons ha-1) in a factorial combination in randomized complete block design and replicated three times. Thus, there were twenty (20) treatment combinations. Treatments were assigned to each plot randomly. The gross plot size of each experimental plot was 10.08 m2 (3.6 m × 2.8 m).

Soil Sampling and Analysis

Soil sample was taken at a depth of 0-30 cm from randomly selected spots in Z pattern across the experimental field with five spots collected per plot before planting and after harvest from each plot by using auger. From the collected soil samples one composite sample before planting and twenty composite samples after harvest were prepared by bulking of the soils collected from similar treatments of different block and minimized to the number of treatments per block for analysis to determine the physico-chemical properties of the soil of the experimental site. The samples were air-dried, thoroughly mixed and ground and sieved to pass through a 2 mm sieve for analysis of soil nutrients and finely pounded to pass 0.2 mm for organic matter analysis. From this mixture, a sample weighing 1 kg was filled into plastic bag and taken to Nekemte soil laboratory for the analysis. The soil samples were analyzed for soil texture, total nitrogen, pH, organic matter, available phosphorus, exchangeable Al and cation exchange capacity (CEC).

Soil particle size distribution (soil texture) was determined in the laboratory by using Bouyoucos hydrometer method as described by Day (1965). Total nitrogen was determined following kjeldahl procedure as described by Cotteinie (1980); the soil pH was measured with digital pH meter on a 1:2.5 soil: water suspension after the suspension was stirred using an automatic stirrer for 30 minute (Page, 1982); organic carbon was determined by the oxidation of organic carbon with potassium dichromate (K2Cr2O7) in which the reactions were facilitated by the heat generated two volume of concentrated H2SO4 and one volume of 1 N K2Cr2O7 solution according to Walkley and Black method as described by Allison (1965).

The available phosphorus was measured using Bray II method by shaking the soil samples with extracting solutions of 0.03 M ammonium fluoride in 0.1 M hydrochloric acid as described by Bray and Kurt (1945); Exchangeable Ca was measured from the extract with atomic absorption spectrophotometer. Exchangeable acidity (Al and H) was determined from a neutral 1 N KCl extracted solution through titration with standard NaOH solution based on the procedure described by McLean (1965). The parameters analyzed after harvesting the treatments were available phosphorus, pH, calcium and exchangeable Al.

RESULTS AND DISCUSSION

Soil Physico-Chemical Properties of Experimental Site

From the soil analysis result before sowing it was apparent that the soil textural class was sandy clay loam with constituents of sand (53%), clay (19%) and silt (28%) which is ideal for groundnut as the crop is grown mostly on light-textured soils ranging from coarse and fine sands to sandy clay loams (Onwueme and Sinha, 1991). The soil pH (H2O) of 5.31 rated as acidic, total nitrogen (0.275%) is as medium, available phosphorus (2.34 mg kg-1) as low, exchangeable calcium (5.379 cmolc kg-1) as moderate according to the classification by Landon (1991) and Aluminium concentration of 1.4 cmolc kg-1 as very high according to the rating of Moore (2001) (Table 1). Thus, moderate to low mineral content of the soil implied that there was necessity of applying nitrogen, phosphorus and calcium to the experimental plot of the study area.

Table 1. Major soil physico-chemical properties of the experimental site before planting

Soil characters	Value	Rating	Reference
A. Particle size distribution			
Sand (%)	53		
Silt (%)	28		
Clay (%)	19		
Textural class		Sandy clay loam	
B. Chemical analysis			
Soil pH	5.31	Acidic	Landon (1991)
Organic matter (%)	6.3	High	Landon (1991)
Total N (%)	0.275	Medium	Landon (1991)
Available P (mg kg^{-1})	2.34	Low	Landon (1991)
Exchangeable Ca ($cmol_c$ kg^{-1})	5.379	Moderate	Landon (1991)
Exchangeable Al ($cmol_c$ kg^{-1})	1.4	Very high	Moore (2001)

The analysis of the experimental soil after harvest for pH, exchangeable Aluminum, exchangeable Ca, available phosphorus and total nitrogen is indicated in Table 3. The result revealed that exchangeable Ca, available phosphorus and total nitrogen were increased while exchangeable aluminum decreased after the application of lime and phosphorus to the experimental plot. However, the range of pH change was only from 5.31 to 5.66 with treatment of the highest rate of 3.75 ton lime ha-1 which could be due to the inactivation of aluminum and iron which correspondingly increased the level of soil pH (Mesfin, 2007).

This small change might be due to high organic matter content of the soil that influences the change in pH which is attributed by its high buffering property. During this situation the soil could resist sharp change in pH with the addition of bases. The other reason might be when the exchangeable site was saturated with basic cations further addition of the basis might less increase the cation fixed to the sites. In this regards, Mesfin (2007) reported the larger the clay and organic matter content, the higher the cation exchange capacity and the greater the buffer capacity.

The result obtained from composited soil analysis showed that the treatments with 23 kg P2O5 and lime rate of 3 ton ha-1 gave an increase of 0.56% pH, 82.62% Ca and 94.66% available phosphorus over the control (Table 2). This implies that lime application possibly increased the pH, calcium content of the soil and available phosphorus so that groundnut utilized the nutrients for proper growth and development that lead to higher yield. In agreement with this result, Nekesa (2007) described that lime improves the crop responses to fertilizers by improving nutrient availability and uptake especially phosphorus, reducing aluminum (Al) toxicity and promoting the activities of such desirable organisms as rhizobia bacteria that fix nitrogen for legumes.

On the other hand, the application of 3 ton lime ha-1 to the soil reduced Al3+ level by 92.65% relatively from 1.4 cmolc kg-1 before planting to 0.103 cmolc kg-1 Al3+ after harvest of the crop. Moreover, the addition of 3 tons lime and phosphorus rate of 23 kg P2O5 ha-1 increased the level of Ca in the soil by 50.20% from 5.379 to 8.079 cmolc kg-1 and phosphorus by 83.79% from 2.24 to 4.117 mg kg -1 after harvest of the crop (Table 2). This was probably correlated with yield increase over the control treatment because of Ca supply and thereby enhancing the availability of phosphorus of the plot where lime was added. In agreement with this result, Barasa et al. (2013) stated that use of lime alone or triple super phosphate in combination with lime increased soil nutrients P and Ca required for plant growth either from direct release from the inputs or improving the solubility of phosphorus from insoluble Al and Fe compounds which are commonly associated with acid soils. Similarly, Mesfin (2007) described liming inactivated aluminum and iron in acidic soil which resulted in increased phosphate availability to plants.

Similarly, the application of the highest rate of 3.75 ton ha-1 lime lowered the Al3+ level by 94.07% from 1.4 to 0.083 cmolc kg-1, whereas increased Ca content of the soil by 60.23% from 5.379 to 8.619 cmolc kg-1 and addition of highest rate of 57.5 P2O5 kg ha-1 at this lime rate increased the phosphorus in the soil by 36.79% from 2.24 to 3.064 mg kg -1 after harvest, respectively (Table 2). The reduction of Al after the application of lime probably associated with inactivation of Al and Iron from the soil exchangeable sites due to the saturation of sites with bases and decreasing solubility potential of Al when pH of the soil raise.

Table 2. Percent change of soil pH, exchangeable calcium (Ca) and Aluminum (Al) and available phosphorus (P) after harvest of the crop in response to liming and phosphorus application

When 3 ton lime and 23 kg P_2O_5 ha^{-1} applied			
Soil chemical analysis	Before planting	After harvest	% change
pH	5.31	5.34	0.56
Exch. Ca ($cmol_c$ kg^{-1})	5.379	8.079	50.20
Exch. AL ($cmol_c$ kg^{-1})	1.4	0.103	92.65
Avail. P (mg kg^{-1})	2.24	4.117	83.79
When 3.75 ton lime and 57.5 kg P_2O_5 ha^{-1} applied			
pH	5.31	5.66	6.60
Exch. Ca ($cmol_c$ kg^{-1})	5.379	8.619	60.23
Exch. AL ($cmol_c$ kg^{-1})	1.4	0.083	94.07
Avail. P (mg kg^{-1})	2.24	3.064	36.79

Table 3. Soil chemical property of experimental field at Haro Sabu after harvest

Treatments			Exch. acidity $cmol_c$ kg^{-1} and exch. Cations					
	Lime ton ha^{-1} and P (kg ha^{-1})	pH (H_2O)	Acidity (Al^{3+})	Ca	Mg	Av. P (mg kg^{-1})	Total N(%)	Organic matter (%)
t1	0, 0	5.31	1.400	4.424	2.217	2.115	0.390	7.802
t6	2.25, 0	5.33	0.080	8.638	2.511	2.009	0.390	7.807
t11	3, 0	5.35	0.164	7.495	2.772	4.107	0.417	8.334
t16	3.75, 0	5.47	0.206	8.020	1.131	2.056	0.403	8.063
t2	0, 11.5	5.31	0.103	8.218	2.513	4.103	0.423	8.466
t7	2.25, 11.5	5.32	0.246	7.689	1.845	2.050	0.391	7.828
t12	3, 11.5	5.36	0.124	7.619	2.626	2.059	0.411	8.216
t17	3.75, 11.5	5.51	0.199	9.718	3.426	4.984	0.471	9.428
t3	0, 23	5.28	0.021	8.704	2.369	2.060	0.390	7.794
t8	2.25, 23	5.32	0.062	8.407	2.358	4.101	0.391	7.828
t13	3, 23	5.34	0.103	8.079	2.058	4.117	0.389	7.788
t18	3.75, 23	5.49	0.226	7.182	2.514	4.104	0.388	7.764
t4	0, 46	5.31	0.062	8.930	3.079	4.106	0.406	8.120
t9	2.25, 46	5.34	0.165	9.298	1.653	2.066	0.426	8.527
t14	3, 46	5.45	0.121	8.907	2.480	2.024	0.418	8.355
t19	3.75, 46	5.53	0.041	9.309	0.617	2.057	0.400	7.995
t5	0, 57.5	5.29	0.160	8.362	1.702	2.003	0.382	7.646
t10	2.25, 57.5	5.33	0.021	9.174	1.668	4.170	0.394	7.888
t15	3, 57.5	5.48	0.000	9.629	0.154	6.146	0.359	7.187
t20	3.75, 57.5	5.66	0.083	8.619	3.148	3.064	0.405	8.094

t = treatment, pH= negative logarithm of hydrogen ion, Al3+ = exchangeable Aluminum, Ca= exchangeable Calcium, Mg= exchangeable Magnesium, Av.p = available phosphorus

CONCLUSION

Soil acidity affects plant growth by reducing nutrient availability such as calcium and magnesium supply and uptake of phosphorus as well due to its fixation. Liming soil acidity particularly on legume has the principal contribution of improving crop responses to fertilizers by improving nutrient availability and uptake especially phosphorus, reducing aluminum(Al) toxicity and promoting the activities of such desirable organisms as rhizobia bacteria which fix nitrogen for legumes. Liming increase the calcium content of the soil which is important for groundnut pod filling by creating proper pH for the crop to take the nutrients around root zone.

REFERENCES

Abdenna Deressa, Negassa Chewaka and Tilahun Geleto. 2007. Inventory of Soil Acidity Status in Crop Lands of Central and Western Ethiopia. "Utilisation of diversity in land use systems: Sustainable and organic approaches to meet human needs"

Allison, L.E. 1965. Organic carbon pp. 1367-1378. In. Black, D.D. Evans,J.L. White, L.E. and Ensiminger, F.E. Clark, (eds.). Methods of soil analysis. Am. Soc. Agron. Monograph No. 9, Madison, Wisconsin, USA.

Barasa, J.N., Omami, E.N., Okalebo, J.R. and Othieno C.O. 2013. Effect of Lime and Phosphorus Fertilizer applications on performance of French Beans in Uasin Gishu District, Kenya. Global Journal of Biology, Agriculture and Health Science, 2(3):35-41.

Bray, R.H., and Kurtz, L.T. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Science, 59:39-45.

Cotteinie, A. 1980. Soil and Plant Testing as a Base of fertilizer Recommendations. Soils Bulletins, No. 38, FAO, Rome.

Day, P.R. 1965. Hydrometer method of particle size analysis In: C.A. Black (ed.). Methods of soil analysis. Am. Soc.agron. No.27. Madison. Wisconsin. pp. 562-563.

Landon, J. R. 1991. Tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and sub tropics. Longman Scientific and Technical, Longman Group, UK Ltd.

McLean, K.O. 1965. Aluminum. pp. 978-998. In: C.A. BLACK (Ed.) Methods of soil analysis: Agro No. 9. Part 2. Am soc. Agron, Madison, Wisconsin, USA.

Mesfin Abebe. 2007. Nature and management of acid soils in Ethiopia. www.eiar.gov.et/Soil/soils_acid.pdfon grain legumes Addis Ababa Ethiopia. Accessed on March 24, 2014.

Moore, Geoff. 2001. Soil Guide: A Hand Book For Understanding and Managing Agricultural Soils. Compiled and Edited By Geoff Moore, Bulletin 4343.

Nekesa, A.O. 2007. Liming Effects of Minjingu Phosphate Rock and Agricultural Lime on Maize, Groundnut and Soybean yields on acid soils of Western Kenya. .M.Sc. Thesis, Moi University .Eldoret Kenya.

Onwueme, I.C. and Sinha, T.D. 1991. Field crop production in Tropical Africa, Principles and practice, CTA (Technical center for agriculture and rural cooperation) The Netherlands.

Page, A.L. 1982. Methods of soil analysis. Part II. Chemical and microbiological properities. Am. Soci.of agron. Mandison. USA. pp 62-67.

Ranjit, R. 2005. Response of Groundnut genotypes to lime and Phosphorus levels in Coastal Alluvial Soil of North Karnataka. Published M.Sc Thesis submitted to the Department of Soil Science and Agricultural Chemistry College of Agriculture, University of Agricultural Sciences, Dharwad acid soil in Congo.

Workneh Bekere, 2013. Liming Effects on Yield and Yield Attributes of Nitrogen Fertilizer and Bradyrhizobia Inoculated Soybean (Glycine max L.) Grown in Acidic soil at Jimma, South Western Ethiopia. Journal of Biology, Agriculture and Healthcare, 3(14): 44-46, http://www.iiste.org/: Accessed on March 16, 2014.