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Resurgence of soil acidity problem and the associated available phosphorus dearth over time after lime amendment in soybean production at Bako area, Western Ethiopia

Derib Kifle

Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, P O box 31, Ethiopia

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A field experiment study was carried out at Bak Agricultural Research Center during 2012-2015 cropping seasons to investigate the duration of lime reaction in the soil and to determine the optimal level and frequency of lime applications and to identify economically viable mixes of lime and P fertilizer in improving soybean productivity and acidic properties of the soil. Factorial combinations of four lime levels (2.3, 3.45, 4.6 and 5.75 t ha^{-1}) and four P rates (11.5, 23, 34.5 and 46 kg P_2O_5 ha^{-1}) were laid out in Randomized Complete Block Design (RCBD) with three replications. The results of the study showed that the highest grain yield (4.37 tons ha-1) was recorded from the use of sub optimal (75% rec.) amount of P_2O_5 with slightly over optimal (125% rec.) level of lime Similarly, the interaction of lime application by cropping season was significantly different for seed yield where the maximum mean grain yield of 3.87 tons ha^{-1} was obtained in the second cropping season improving soybean productivity by 148% compared to the control. In the other standpoint, the soil laboratory analytical result after harvest showed that the highest soil pH (6.22) was recorded from the combination of 5.75 t lime ha^{-1} and 23 kg ha^{-1} of P_2O_5 Conversely, the exchangeable acidity was significantly reduced to 0.52 cmol (+) kg^{-1} due to application of the highest dose of lime(5.75 t lime ha-1) that improved the potential acidity level of the soil by 196%. The highest soil available P (21.99 mg kg^{-1} of soil) was recorded from the plots treated with 5.75 tons ha^{-1} of lime and 46 kg ha-1 P_2O_5. The soil test result showed that all tested soil parameters were affected by cropping season in which the highest record was obtained during the second cropping season after lime application which afterward witnessed a decreasing tendency during the third and fourth years after lime application indicating that the subsequent liming intervention should be made at this time to sustain the soil and soybean productivity of acidic soils across these parts of the country.

Keywords: Soil acidity, soil fertility, liming frequency, optimal combination

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INTRODUCTION

Soybean is an important multipurpose crop that has recently been introduced to smallholder farmers in Ethiopia as source of food and protein source for resource poor farmer who cannot afford to obtain dairy products. This pulse crop is currently serving as an income generating commodity and is being utilized as raw material in food processing industry in the country (Mekonnen and Kaleb, 2014). An increasing importance of soybean in Ethiopia is also shown in agriculture through counteracting depletion of plant nutrients especially nitrogen in the soil resulting from continuous mono-cropping of cereals, especially maize and sorghum, through biological nitrogen fixation, due to the presence of symbiotic bacteria Rhizobium japonicum in their roots (Sanginga, 2003) thereby contributing to increasing soil fertility .

However, acid soil infertility which has become a serious threat to crop production in most highlands of Ethiopia specifically in western part of Oromia caused by leaching of exchangeable cations (Ca2+, Mg2+, K+) and accumulation of high concentration of Al and other soil fertility degradation attributes are the main factors that adversely affect the soybean production in the country (Workneh, 2013).In acid soils, availability of phosphorus, biological nitrogen fixation, and microbial activity are reduced which in turn affects soybean development and yields. Reduced availability of Nitrogen (N) and Phosphorus (P) in predominantly acidic soils is responsible for reduced soybean performance through reduced photosynthesis and early root development, low microbial activity and poor nitrogen fixation, leading to low yields (Amba *et al*. 2011; Kamara *et al*. 2008).

Acidic unproductive soils maybe corrected through liming by reducing soil acidity to a level at which crop can produce its potential. Thus, liming acid soil makes the soil environment better for leguminous plants and associated microorganisms as well as increase concentration of essential nutrients by raising its pH and precipitating exchangeable aluminum (Kisinyo *et al*., 2005).The amount of lime required to adjust the pH of the soil and its change over time in response to lime application depends upon the soil type, initial pH value of the soil and lime quality (Foth and Ellis, 1997). Soils with a high clay and organic matter content (greater reserve acidity) will require greater amounts of lime to neutralize acidity than a sandy soil lower in clay content and organic matter (lower reserve acidity) given that each soil has the same pH (Joseph., 2019). Soil pH declines faster in sandy (low CEC) soils than in soil with moderate to high clay content. The frequency at which lime is applied depends on soil type and on soil drainage. One of the principal soil characteristic related to its type which is responsible in determining the rate and frequency of liming is cation exchange capacity (CEC). In general, change in soil pH over time in response to lime application depends upon the soil type, lime rate and lime quality and drainage (Foth and Ellis, 1997). A soil that is poorly drained requires less frequent liming than a well-drained soil because of the reduced leaching of basic cations under poorly drained conditions (Anderson *et al*. 2013). Thus, the purpose of the present study was to study the relationships and magnitude of interaction between fertilizer and lime factors on yield of soybean and to investigate soil acidity change over time in response to application of optimal amount of agricultural lime and chemical fertilizer.

MATERIALS AND METHODS

Site description

The experiment was conducted at Bako Agricultural Research Center during 2012-2015 cropping seasons. The Center's experimental field is located at a latitude of 9^0 6' N and longitude of 37^0 9' E and at an altitude of 1650 m above sea level (Figure 1). The location has warm humid climate with annual mean minimum and maximum air temperatures of 13.5 and 29.7^0C, respectively. The area received average annual rainfall of 1425mm (2012), 886 mm (2013) and 1431mm (2014) with maximum precipitation being received in the months of May to August (Figure 2). However, monthly distributions of the rain fall through the cropping seasons were not similar (Metrological station of the centre). The soil of the experimental site was reddish-brown, Nitisol, which is strongly acidic in reaction with a pH range of 5.0-5.4 according to the rating by Jones (2003). The area is a mixed farming zone and is one of the most important soybean (*Glycine max L.*) growing belts in Ethiopia, in which cultivation of maize (*Zea mays L.*), finger millet (*Eleusine coronata*), common bean (*phoseolus vulgaris L.*) and to some extent tef (*Erograstis tef*), are common.

Soil sampling and analysis

Soil samples (0–20 cm) were collected from the whole experimental field before lime application and from every experimental unit after each harvesting season randomly in zigzag pattern using an auger and core sampler. Soil samples were air-dried; gravels and non-decayed plant debris were removed and were ground to pass through 2mm and 0.5 mm screen prior to analysis. Soil pH was determined potentiometrically using pH meter with combined glass electrode in a 1:2.5 soil to water supernatant suspension (Van Reeuwijk, 1992). The base titration method which involves saturation of the soil sample with 1M KCl solution and titrating with sodium hydroxide was employed to determine exchangeable acidity as described by (Rowell D, 1994).. Available soil phosphorus was extracted by the Bray II procedure (Bray and Kurtz, 1945) and determined colorimetrically by spectrophotometer.

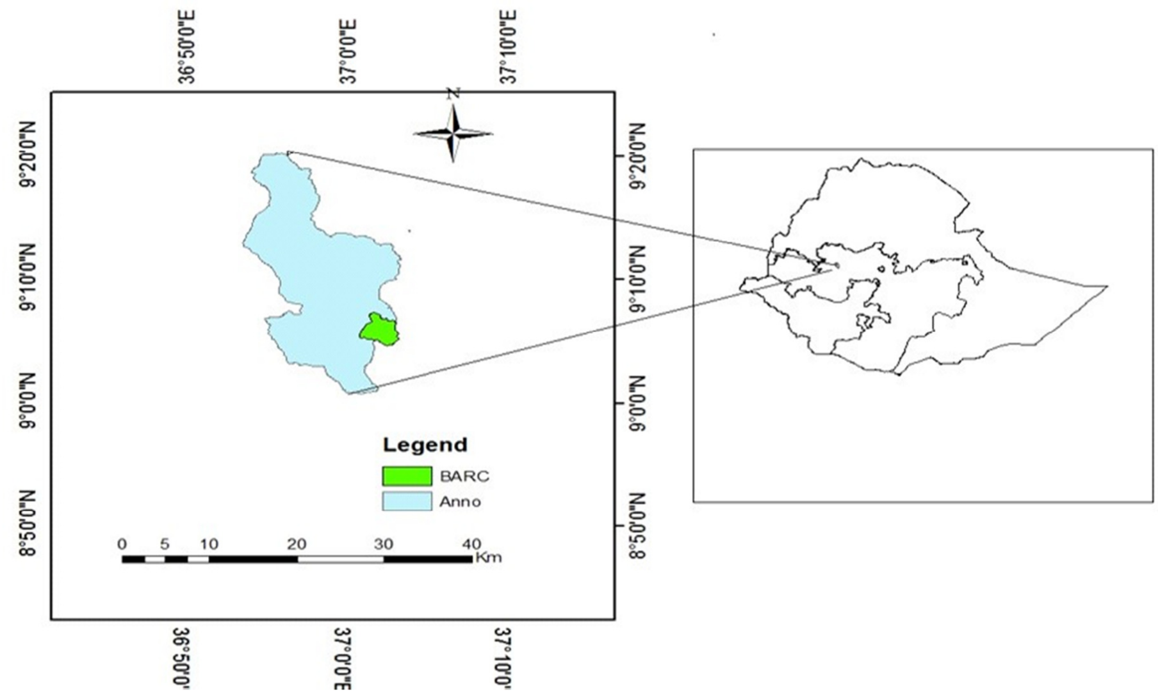

Figure 1. Map of the study area: Bako Agricultural Research Center

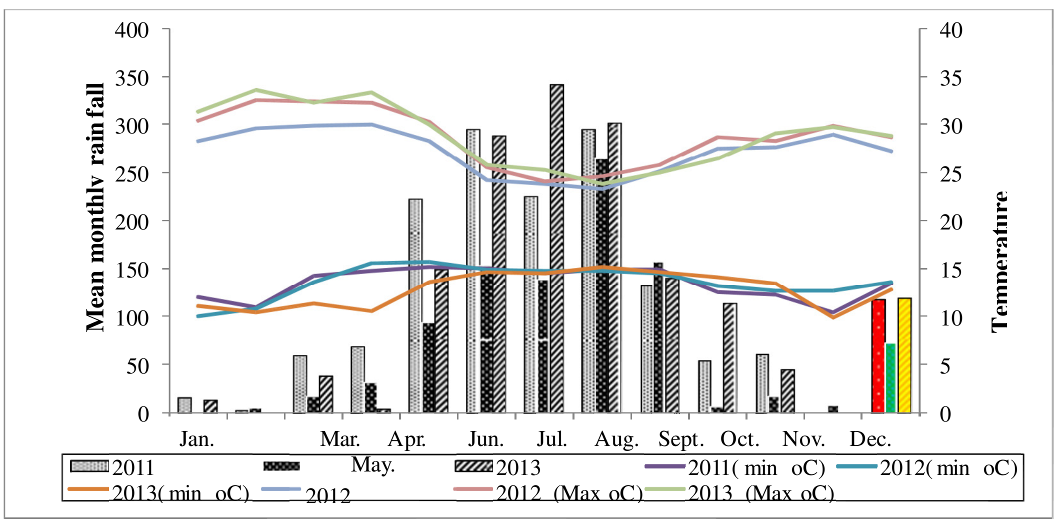

Figure 2: Monthly rainfall, minimum and maximum temperature of crop growing seasons in Bako Agricultural Research Center (2011-2013)

Lime rating and fertilization

The amount of lime was determined based on the soil's exchangeable acidity (Al^{+3} plus H^{+1}) and bulk density with in 0.15m depth of the soil adapted from (Kamprath, 1984) for liming acid mineral soils. Soil acidity ameliorant used in the experiment was calcite limestone of 95 CCE (Calcium Carbonate Equivalent) and fineness of 90 microns, while, the fertilizer source was TSP (Tri-Super Phosphate).The recommended rate of lime and P were 4.6 tons $ha^{-1}$and 46 kg ha^{-1}, respectively.

Experimental design and procedures

The experiment comprised four levels of lime (2.3, 3.45, 4.6 and 5.75 t ha^{-1}) which represented 50%, 75%, 100% and 125% recommended amount of lime respectively and four P rates (11.5, 23, 34.5 and 46 kg ha^{-1} P_2O_5)

combined factorially with one check and two controls, constituting a total of nineteen treatments which was laid out in RCBD with three replications. The linear model for the Two Factor Randomized Complete Block Design: $Y_{ijk} = \mu + \alpha_i + \beta_i + \Upsilon_k + \alpha\Upsilon_{ik} + \varepsilon_{ijk}$ where, Y_{ijk} = the value of the response variable; μ = Common mean effect; α_i = Effect of factor A; β_i = Effect of block; Υ_k = Effect of factor B; $\alpha\Upsilon_{ik}$ = Interaction effect of factor A & factor B and ε_{ijk} = Experiment error (residual) effect

Lime was surface applied and incorporated with the soil by hand 60 days before planting. The test crop was a soybean variety of 'Boneya' recommended for Western Oromia agro ecological zone which was planted at intra and inter spacing of 40cm x 5 cm in gross plot area of $16m^2$ after the P fertilizer had been applied per row and mixed with soil. Net plot area of $12.8m^2$ was used for crop data collection at harvesting. Harvesting was done when 95% of the plants reached harvestable maturity. At physiological maturity, the above ground dry biomass of ten pre-tagged plants from the destructive rows was measured after oven drying the harvested produce at constant weight at 70°C for 48 hours. For obtaining the total aboveground dry biomass, the dry biomass per plant thus obtained was multiplied with total number of plants in net plot area and converted in to kg ha^{-1}. Seed yield was weighed and adjusted to 10% moisture content standard as recommended by Biru (1979) according to the formula;

Adjusted yield (g/plot) = Measured yield × (100 – sample moisture content/100 – standard moisture content)

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Data analysis

Data were analyzed using SAS version 9.1 (SAS, 2004) computer software and were subjected to ANOVA to determine significant differences among factors and their interactions. Means were separated using LSD test. For all analyzed parameters, $P < 0.05$ was interpreted as statistically significant.

RESULTS AND DISCUSSION

Table 1. Some physical and chemical properties of the soil of experimental site

Parameters	Test Result	Rating	Source
Sand (%)	45.28		
Clay (%)	38.36		
Silt (%)	16.36		
Textural Class	Sandy clay loam		
pH H_2O (1:25)	5.05	Strongly acidic	Landon (1991)
Exchangeable acidity (meq/100 g soil)	2.29	High	Dinkins (2007)
Available phosphorus (ppm)	8.52	Low	Jones (2003)

Effects of lime and P fertilizer on soybean grain yield

The result of the study showed that seed yield of soybean was significantly affected by interaction of lime with P fertilizer application. A combination of lime and phosphorus fertilizer resulted in higher grain yield than that with lime or P used independently. The highest grain yield (4.37 tons ha-1) was recorded from the use of sub optimal (75% rec.) amount of P_2O_5 with slightly over optimal (125% rec.) level of lime, whereas the lowest grain yield (1.72 tons ha^{-1}) was recorded from the absolute control with no lime amendment and fertilizer input (Table 2) which gave a grain yield advantage of 154% over the no input experimental unit. This could be due to liming that reduced the exchangeable acidity (neutralizing the effect of Al^{3+} and H^+ , raising the soil pH), enhanced soybean root performance, affected the solubility and availability of most of the plant nutrients, raised the level of exchangeable base status and improved soil structure. The results of the present study are in compliance with the work of Mesfin *et al.* (2014) who had reported the highest seed yield (1488.4 kg ha-1) of haricot bean from the combination of 30 kg P_2O_5 ha^{-1} and the recommended amount of lime. Comparable investigation on soybean by Vongvilay *et al.* (2009) illustrated that liming had beneficial effects on soybean where yield of soybean was improved significantly compared with the control. The seed yield obtained from the experimental plot that received recommended lime alone (2.06 tons ha^{-1}) was lower than that of the plot

Table 2. Seed yield of soybean (t ha^{-1}) as affected by the interaction of P fertilizer and lime application

P_2O_5 (kg ha^{-1}),	Lime rate (t ha^{-1})				No lime
	2.3	3.45	4.6	5.75	
11.5	2.56	2.02	3.30	3.88	
23	2.70	3.09	3.66	3.76	
34.5	2.75	3.27	4.02	4.37	
46	2.97	3.40	4.16	3.91	2.32
No fertilizer			2.06		1.72
CV (%)17.46					
LSD (5%) 226					

Table 3. Seed yield as affected by the interaction of lime application and cropping season

Cropping season	Lime rate (t ha^{-1})				No lime
	2.3	3.45	4.6	5.75	
Year 1	3.12	3.23	3.48	3.63	2.22
Year 2	2.96	3.32	3.87	3.45	2.14
Year 3	2.84	3.17	3.35	3.33	1.89
Year 4	2.76	2.86	2.92	2.97	1.56
CV (%)17.46					
LSD (5%) 226					

treated with sole recommended P; however, it was significantly higher than that of the control plot (1.72 tons ha^{-1}), the increment of which were 19.76%. Similar findings have been reported by Kamara *et al.* (2008) who found significant effects of lime and P fertilizer on grain yields, The positive effects of lime on soybean productivity could be due to liming which increased soil nutrient availability through mobilization (P) and N fixation by microbial activity in which more crop nutrient demands were met. This result is in concordance to the finding of Andy and Abdullah (2016) that explains application of lime and p fertilizer at similar rate increased seed yield by 166-188% compared to no lime and fertilizer application elucidate that liming alone cannot serve to achieve the maximum potential of an acid soil.

Similarly, the interaction of lime application by cropping season was significantly different for seed yield where the maximum mean grain yield of 3.87 tons ha^{-1} was obtained in the second cropping season improving soybean productivity by 148% compared to the control (Table 3). The lowest seed yield which was not significantly different from each other with regard to rate of lime applied was obtained during the fourth cropping season after lime application. Other than the minimum lime rate applied, seed yield during the second production season after lime application was highly significant compared with the third and fourth cropping year after lime application that showed a decreasing tendency of soybean yield over time after lime amendment. Treatments without lime produced significantly the lowest seed yield in each cropping season. This tendency of yield decrease beyond application of lime and P might be attributed to decline of lime reaction through time and imbalance of P with other nutrients due to the altered nutrient availability to growing plants (Gascho and Parker. 2001). This result is in agreement with the finding of Getachew *et al.* (2017) that describes longer years of liming may indicate re acidification of the soil which necessitates re-liming of the soil.

The interacting effect of lime and P fertilizer on selected chemical property of soil

Soil pH and exchangeable acidity

Soil analytical result after harvest showed that the combined use of lime and P fertilizer increased soil pH and exchangeable acidity. The highest soil pH (6.22) was recorded from the combination of 5.75 t lime ha-1 and 23 kg ha^{-1} of P_2O_5 while the lowest soil pH (5.21) was recorded from non lime amended and unfertilized plot which corresponded to an increase of 19.4% over the control(Table 4). Conversely, the exchangeable acidity was significantly reduced to 0.52 cmol (+) kg-1 due to application of the highest dose of lime(5.75 t lime ha-1)and three quarter of recommended P (34.5 kg P_2O_5 ha^{-1}) that improved the potential acidity level of the soil by 196%. The raise of soil pH and decline of the soil exchangeable acidity might be due to reduction in H^+ and

Al^{+3} ions concentration in the soil solution by buffering ability of applied lime. The result of this study is in conformity to the observation of Buni (2014) who reported that soil pH increased from 5.03 to 6.72 and exchangeable acidity (EA) was significantly reduced due to the application of 3.75 t lime ha-1 on Nitisol with an inherent property of high P fixation in southern Ethiopia. A concordant examination was done by Desalegn *et al.* (2017) which showed that Application of 0.55, 1.1, 1.65 and 2.2 t lime ha-1 decreased Al^{3+} by 0.88, 1.11, 1.20 and 1.19 mill equivalents per 100 g of soil, and increased soil pH by 0.48, 0.71, 0.85 and 1.1 units, respectively. The findings observed on soil pH and the exchangeable Al changes in soil agree with the findings of many authors (Caires *et al*. 2008, Sadiq and Babagana, 2012, Chimdi *et al*. 2012) who reported the increase of 0.4 to 0.9 units of soil pH after lime application and the reduction of exchangeable Al and Aluminium saturation to adequate levels following application of lime in acidic soil.

Soil available phosphorus

According to the result of the current study, the highest soil available P (21.99 mg kg^{-1} of soil) was recorded from the plots treated with 125 % rec. lime (5.75 tons ha^{-1}) and 100 % rec. P (46 kg ha^{-1} P_2O_5) while the lowest soil available P (10.3 mg kg^{-1} of soil) content was recorded from the non treated control plots. This sizeable increase in available P could have been caused by quick action of lime in improving soil acidity and enhancing microbial activity for mineralization of organic P when optimum pH is attained and hence phosphorus availability is realized (Kisinyo *et al*.2012). Another reason for this scenario might be the effect of external application of P fertilizer which is better extricated from fixation as insoluble phosphates due to the lime conditioned environment of the soil. In line with this result, Kisinyo *et al.* (2016) pointed out that both lime and P fertilizer applications are important to enhance soil available P in acid and P deficient soil. Similarly, Fageria *et al.* (2007) reported an increase of soil phosphorus as pH increased due to liming from 5.0 to 6.5, due to release of P ions from Al and Fe oxides, which are responsible of P fixation. Anetor and Akinrinde (2007) reported that un amended soil remained acidic (pH 4.8), but liming raised pH (6.1-6.6), and resulted in maximum P release (15.1-17.3 mg kg-1) compared to un-amended soil (4.2-7.1 mg P kg-1) where application of lime and P increased plant tissue P, Ca and Mg concentrations

Table 4. Soil acidity attributes and soil available phosphorus content as affected by the interaction of lime and P fertilizer applied

Treatments	pH	Ex.Ac.(cmol (+) kg^{-1})	Ex.Al.(cmol (+) kg^{-1}).	Av.P. (mg kg^{-1} of soil)
5.75 t ha^{-1} lime + 11.5 kg $ha^{-1}P_2O_5$	5.88^{bc}	0.53^{h}	0.08^{def}	17.46^{de}
5.75 t ha^{-1} lime + 23 kg $ha^{-1}P_2O_5$	6.22^{a}	0.69^{efg}	0.06^{ef}	16.76^{e}
5.75 t ha^{-1} lime + 34.5 kg $ha^{-1}P_2O_5$	6.05^{ab}	0.52^{h}	0.16^{cd}	18.17^{de}
5.75 t ha^{-1} lime + 46 kg $ha^{-1}P_2O_5$	5.88^{cb}	0.72^{d-g}	0.05^{f}	21.99^{a}
2.3 t ha^{-1} lime + 11.5 kg $ha^{-1}P_2O_5$	5.55^{e-h}	0.88^{cb}	0.35^{b}	16.88^{de}
2.3 t ha^{-1} lime + 23 kg $ha^{-1}P_2O_5$	5.76cd	0.71^{d-g}	0.13^{c-f}	21.47^{ab}
2.3 t ha^{-1} lime + 34.5 kg $ha^{-1}P_2O_5$	5.74^{efg}	0.83^{bcd}	0.078^{def}	18.22^{cde}
2.3 t ha^{-1} lime + 46 kg $ha^{-1}P_2O_5$	5.38^{h}	1.12^{a}	0.44^{a}	21.36^{ab}
3.45 t ha^{-1} lime + 11.5 kg $ha^{-1}P_2O_5$	5.69^{c-f}	0.72^{def}	0.128^{c-f}	18.69b-e
3.45 t ha^{-1} lime + 23 kg $ha^{-1}P_2O_5$	5.53^{fgh}	0.96^{b}	0.13^{c-f}	18.84^{b-e}
3.45 t ha^{-1} lime + 34.5 kg $ha^{-1}P_2O_5$	5.5^{gh}	0.79^{cde}	0.19^{c}	19.89^{a-d}
3.45 t ha^{-1} lime + 46 kg $ha^{-1}P_2O_5$	5.66^{d-g}	0.89^{cb}	0.07^{ef}	16.58^{e}
4.6 t ha^{-1} lime + 11.5 kg $ha^{-1}P_2O_5$	5.72^{cde}	0.59^{gh}	0.15^{cde}	21.3^{abc}
4.6 t ha^{-1} lime + 23 kg $ha^{-1}P_2O_5$	5.7^{c-f}	0.64^{fgh}	0.09^{def}	17.11^{de}
4.6 t ha^{-1} lime + 34.5 kg $ha^{-1}P_2O_5$	5.6^{d-g}	0.71^{d-g}	0.08^{def}	19.13^{a-e}
4.6 t ha^{-1} lime + 46 kg $ha^{-1}P_2O_5$	5.65^{d-g}	0.69^{efg}	0.15^{cde}	19.85^{a-d}
4.6 t ha^{-1} lime	5.75	0.88	0.15	17.4
46 kg $ha^{-1}P_2O_5$	5.28	1.67	1.37	18.35
Control	5.21	1.54	0.96	10.3
CV	4.09	18.3	21.06	20.15
LSD	0.15	0.11	0.07	2.18

LSD (0.05) = Least Significance Difference at 5% of Probability level, Ex.A = Exchangeable Acidity, Ex. Al = Exchangeable Aluminum, Av.P.= Available Phosphorus. Means within a column followed by the same letter (s) or with no letter are not significantly different.

Soil acidity indices and available P change over time in response to lime and P fertilizer application

The change in soil acidic property over time in response to lime and P application after harvest was specified in table 5, 6, 7 and 8. The laboratory analytical result showed that all tested soil parameters were affected by cropping season in which the highest record for these properties was obtained during the second cropping season after lime application. Certainly, most of the records for these parameters showed decreasing tendency during the third and fourth years after lime application. In all seasons, the application of lime alone recorded higher value for the most of soil characteristics except soil phosphorus when compared to the sole application of recommended rate of P fertilizer. This is in agreement with the observation of Kiflu *et al*. (2017) who remarked that the carry over effect of conditioning acid soil with lime is better than its external fertilization in maintaining proper soil process and health in the long run. The other phenomena was observed by the application of lime in combination with P fertilizer where soil pH significantly increased with lime rate after the first cropping season in which the highest values were recorded by application of 5.75 t ha^{-1} of lime. The lowest value of pH which is equivalent to the threshold record was obtained from the minimum dose of lime (2.3 tons ha^{-1}) during the fourth cropping season that explains how soil pH changes over time if soils are continuously cropped but not limed. Application of lime and its residual effect highly decreased exchangeable acidity and exchangeable Al^{+3} as the level of applied lime rates increased. The present findings are in agreement with Malhi *et al*. (1983) who reported that application of lime at the rate of 2 t ha^{-1} significantly increased topsoil pH values from 4.6 to 6.0 while exchangeable acidity and Al^{+3} had significantly reduced in the first 3 cropping seasons which indicated that lime application had significantly (P<0.05) decreased soil acidity sharply in the first year and thereafter slightly amplified over years.

Table 5. Soil pH as affected by the interaction of liming and cropping season

Cropping season	Lime rate (t ha^{-1})					
	2.3	3.45	4.6	5.75	Rec. lime	Rec.P
2012	5.08	5.53	5.49	5.65	4.93	4.54
2013	5.07	5.47	5.75	6.15	5.04	4.57
2014	5.06	5.55	5.59	5.73	5.01	4.78
2015	5.04	5.16	5.24	5.33	5.17	4.96
CV (%)4.09						
LSD (5%)0.094						

On the whole, the liming treatments reduced soil exchangeable acidity of the experimental field in all seasons (Table 6) that reduced the initial value (2.29 cmol (+) kg^{-1}) by 54.7% at the minimum during the last (fourth) cropping season. This was substantiated by observation of Athanase (2013) that suggest that it is rarely necessary to lime acid soil more frequently than every 3 years. The experimental unit that received 5.75 tons ha^{-1} of lime during the second cropping season was most effective in reducing exchangeable acidity that recorded 0.42 cmol (+) kg^{-1} reducing the value by 266% compared to the control. The highest values of exchangeable acidity were observed for the plots treated with P fertilizer alone (2.65 cmol (+) kg^{-1} soil) followed by the plot receiving sole lime (2.1 cmol (+) kg^{-1} soil) during the last (2015) cropping season.

Table 6. Soil exchangeable acidity as affected by the interaction of liming and cropping season

Cropping season	Lime rate (t ha^{-1})					
	2.3	3.45	4.6	5.75	Rec. lime	Rec.P
2012	0.82	0.77	0.77	0.72	1.77	1.54
2013	0.72	0.65	0.52	0.42	1.62	2.41
2014	0.94	0.83	0.74	0.61	1.53	2.3
2015	1.48	1.39	1.25	1.18	2.1	2.65
CV (%)19.3						
LSD (5%)0.06						

Table 7. Soil exchangeable aluminium as affected by the interaction of liming and cropping season

	Lime rate (t ha^{-1})					
Cropping season	2.3	3.45	4.6	5.75	Rec. lime	Rec.P
2012	0.1	0.085	0.082	0.07	0.36	1.1
2013	0.089	0.078	0.071	0.065	0.12	1.08
2014	0.177	0.159	0.156	0.127	0.91	1.46
2015	0.61	0.454	0.39	0.328	1.51	1.86
CV (%)71.96						
LSD (5%)0.043						

The result of this study showed that amending acidic soil with lime resulted in significant increase in available P markedly at the post-harvest of 2013 and 2014 seasons in which application of the highest rate (5.75 t/ha) of lime increased the available P content of the soil by 156% over the control (Table 8). The result of this study is in concomitance with the findings of Anetor and Akinrinde. (2007) who reported that the mean P concentration in limed soil sample is higher (20.85 ppm) than before liming (9.14 ppm) which clearly shows highly significant effects of soil acidity adjustment on P availability. The maximal increment were also observed in the treatments of P fertilizer alone (23.3 mg kg-1) and sole lime (15.84 mg kg^{-1}),which corresponded to 126% and 53.7%, in 2013 and 2014 respectively, over the control. The increment of the available P content of the soils with increasing lime rate may be attributed to increasing pH due to liming that could release the unavailable P which was previously fixed with Al and Fe at low soil pH condition. Therefore, agricultural lime added to soil is a profitable soil additive and it hydrolyzes Al and Fe ions that precipitated with P releasing the tied up P in to the soil solution consequently rendering the phosphate ion available for plant uptake. Liming and thus raising the pH of acidic soil across different land use systems generally provide more favorable environments for microbial activities and possibly results in net mineralization of soil organic P (Chimdi *et al.* 2012). In another perspective, the other reason for the increase of soil P might be a result of the residual effects of the applied P fertilizer in every cropping season because of its low mobility in the soil. This is in compliance with observation of Nekesa (2011) that asserted liming can have a P-sparing effect which decreases the fixation of inorganic P by soil colloids and stimulates the uptake of P by plant. The strength of adsorption of phosphate onto soil surfaces is affected by pH and the effect is dependent on the predominant clay minerals and types of organic matter in soils. Generally, adsorption is weakest at neutral pH and increases with increasing acidity where liming of acidic soils reduce the P sorption thus increasing its availabilities. This fact is more emphasized in (Mullins, 2001, Hammond *et al*, 2004) 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 in soils that have been depleted. In general, on acid soils with a low initial pH, it can be expected that extractable P increases after lime application. This is due to the increase of the pH, causing desorption of P from Fe- oxides, Al-oxides and -hydroxides and the dissolution of Fe and Al-phosphates (Haynes, 1984).

Table 8. Soil available phosphorus as affected by the interaction of liming and cropping season

	Lime rate (t ha^{-1})					
Cropping season	2.3	3.45	4.6	5.75	Rec. lime	Rec.P
2012	13.5	14.1	17.15	16.28	11.78	13.86
2013	24.06	26.13	26.39	24.84	13.6	23.3
2014	21.28	23.26	19.8	20.79	15.84	19.24
2015	10.92	12.18	13.54	13.85	13.45	15.06
CV (%)20.15						
LSD (5%)1.54						

CONCLUSION AND RECOMMENDATION

Soil acidity had inherently existed for long time but not well noticed in Ethiopia. It was lately recognized (identified) to be one of soil problem that creates hindrance to productivity in the agricultural sector. The menace of soil acidification cannot be completely eliminated at once; however, preventive measures such as liming can be adopted for the remaining.

Soybean is an important crop that has recently been introduced to small holder farmers in Ethiopia as source of food and protein source and currently serving as an income generating commodity whose production has been practiced in Western part of the Ethiopia and is being utilized as raw material in food processing industry in the country. However, high acid soil infertility due to low soil pH caused by leaching of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) and high concentrations of Al and depletion of major plant nutrients (N,P and others) attributed to continuous cultivation with removal of nutrients by crop, along with inefficient use of production inputs have remained to be the major hindrances to secure needed harvest of this crop.

Thus, a field experiment was conducted during 2012-2015 cropping seasons to investigate the duration of lime reaction in the soil in order to estimate the optimal level and frequency of lime applications to low pH soils and to identify economically feasible mixes of lime and P fertilizer that can maximize the productivity of soybean and improve selected soil chemical properties.

According to the result of the current study, application of lime and P reduced soil acidity, and increased available P in which the higher dose of these inputs increased and maintained longer residual effects on soil pH, exchangeable acidity, exchangeable Al^{3+} available P and grain yield than lower ones. The soil test result showed that all measured soil parameters were affected by cropping season in which the highest record for these properties were obtained during the second cropping season after lime application. Indeed, most of the records for these parameters showed decreasing tendency during the third and fourth years after lime application even though the soil acidity level didn't revert to its horrible past until then which indicated that liming intervention should be made at least in every four or five years to keep soil acidity and soil nutrient level in check for sustainable soybean production in such acidic belt areas of the country.

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