ORIGINAL ARTICLE

Lime application and re-acidification of the reclaimed soil along cropping season and its effect on some soil chemical properties and maize yield in acidic soil of Maize Belt areas of Western Ethiopia

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ABSTRACT

The decline in crop productivity can occur due to acid soil infertility caused by many different factors among which nutrient depletion and mining are the major ones, which in turn partly attributed to leaching of basic cations from the soil surface and the complete removal of crop residues from farmlands for their competitive use as fuel-wood, construction, etc. A five year field experiment was conducted to investigate the effect of lime on selected soil chemical properties, maize yield and lime reaction in the soil in order to determine the optimal level and frequency of lime applications for optimal maize grain yield. The experiment involved five levels of lime (0, 1.86, 2.79, 3.72, and 4.65 t ha^{-1}) with three replications in RCBD. The results of the study showed that lime application was significantly (0.05) affected seed yield where the maximum mean grain yield of 7.02 t ha^{-1} was obtained from the recommended rate of lime in the third cropping season improving maize seed yield productivity by 93% compared to control treatment. Soil analytical result of post-harvest showed that the highest soil pH (5.67) was recorded from 3.72 t ha^{-1} lime in the 3rd year. However, the exchangeable acidity was significantly (0.05) reduced to 0.72 $cmol_{(+)}kg^{-1}$ due to the application of the same amount of lime in the same year that improved the potential acidity level of the soil by 268% than the plot without lime treatment. The highest soil available P (23.32 mg kg^{-1} soil) was recorded from the plot that received 3.72 t $ha^{-1}$of lime. The result of maize seed yield and soil analytical result showed the highest result obtained during the third cropping season after lime application and start to decline after that. This witnessed a decreasing tendency of lime through time indicating that the subsequent liming intervention should be made at the fourth year to sustain the soil fertility and health of acidic soils and maize productivity in the study area and other parts of the country with similar agro ecology.

Keywords: Soil infertility, soil pH, liming frequency, maize productivity

INTRODUCTION

Soil acidity is one of the main factors contributing towards reduced agricultural productivity and its impacts on crop production in the world. Low crop productivity in many regions of the world is mainly caused by low soil pH and high Al content (Chen et al., 2013). The Al toxicity, low pH, exchangeable bases and P deficiency seriously threaten agricultural production under acidic areas. Land and crop productivity are declining while soil acidity is increasing in Ethiopia. Mono-cropping, removal of basic cations by crops and leaching, continual and inappropriate use of acid- forming inorganic fertilizers, and soil erosion have been threats to soil fertility and has been drastically reducing maize crop yields (Tesfa *et al.,* 2001). The decline in soil fertility may also occur because of nutrient depletion and mining, which should be partly attributed to the complete removal of crop residues from farmlands for their competitive use as fuel-wood, construction, etc. These factors lead to progressively lower crop yields, increased costs of production and may end up with land abandonment (Rosenani *et al*., 2003).

Acid soil infertility which has become a serious threat to crop production in most highlands of Ethiopia specifically in the western part of the country caused by leaching of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) and accumulation of high concentrations of Al and other soil fertility degradation attributes are the main factors that adversely affect maize production in the country (Werkineh, 2013). Different researchers reviewed those reddish-brown soils of the Ethiopian highlands are highly deficient in phosphorus (P) induced by the soil's acidic nature. Gupta *et al*. (2013) reported that poor fertility of acid soil is due to a combination of mineral toxicities (Al, Mn, and Fe) and nutrient deficit caused by leaching of P, Ca, Mg, and micronutrients such as Mo, Zn, and B. Considerable grain yield reductions of maize under low soil pH has been reported in numerous studies. Hayati *et al*. (2014) noted that grain yield reduction in acid soils varied from 2.8 to 71%. Tandzi *et al*. (2015) found maize yield reduction under acid soils to be up to 69%.

Liming acidic soil is an option to minimize acidity hazards to the low crop yield and/or total crop failure on acid prune areas. Acidic unproductive soils can be corrected by liming to reduce its acidity to attain its production potential. This makes the soil environment better for crop and beneficial microorganisms as well as increase availability of essential plant nutrients by raising its pH and precipitating exchangeable Al (Kisinyo *et al*., 2005). However, efforts made so far in this line didn't measured up to the alleviation of acid soil infertility confronted in crop production system significantly. This and other related facts to the injurious effect of soil acidity, inspired the need of combating this problem with vigor in the western part of the country through different research undertakings of this sort. Nevertheless, the amount of lime to be added to soil and its re-liming time along the groping season is not well documented. Thus, the purpose of the present study was to investigate the association of lime quantity and duration of its activity in the soil medium, to observe the interactive effect of lime and cropping season on yield of maize and selected chemical properties of the soil and to investigate soil acidity change over time in response to application of different rates of lime.

MATERIALS AND METHODS

Site description

The study was conducted at Gute kebele, Wayu Tuka district of western Oromia national Regional State for five years starting from 2012 cropping seasons. The experimental field is located at Latitude: 9.003^{0} N and Longitude: 36.63^{0} E and at an altitude of 2030 m above sea level (Figure 1). The location has a warm humid climate with annual mean minimum and maximum air temperatures of 11.9 and 24 ^{0}C, respectively. According to Bako Agricultural Research Center Metrological station, the study area has an average ambient humidity of 60%, wind speed of 96 km/hr., the sunshine of 6 hours/day, and radiation of 17.8 MJ/m^{2}/day. The area received average annual rainfall ranging from 886 to 1635 mm with maximum precipitation being received in June to August. The soil of the experimental site was reddish-brown; Nitisol, which is very strongly acidic in reaction with a pH range of 4.5-5.4 according to the rating by Jones (2003). The farming practice in area is a mixed crop livestock farming where the dominant cereal crop is maize (*Zea mays* L.).

Soil sampling and analysis

Soil samples were collected (0–20 cm) from the whole experimental field in zigzag pattern about 45 (assuming the location of plots), auguring points were sampled and were composited to one sample, before lime application and from every experimental unit after each harvesting season randomly using an auger for all soil analyzed parameters except for bulk density used a core sampler. Soil samples were air-dried, ground to pass through a 2 mm screen before the analysis and were taken to Bako Agricultural research laboratory. Soil particle size distribution was analyzed by the hydrometer method (Bouyoucos, 1962). Soil pH was determined potentiometrically using a pH meter with a combined glass electrode in a 1:2.5 (w/v) soil to water supernatant suspension (Van Reeuwijk, 1992). The base titration method which involves saturation of the soil sample with 1 M KCl solution and titrating with sodium hydroxide was employed to determine exchangeable acidity as described by (Rowell, 1994). Available soil phosphorus was extracted by the Bray II procedure (Bray and Kurtz, 1945) and determined colorimetrically by spectrophotometer at 882 nm.

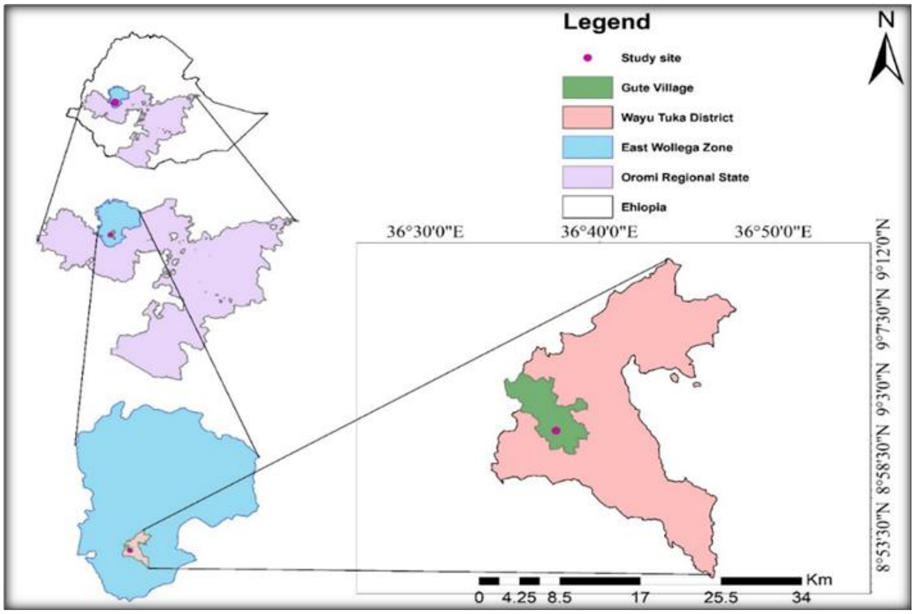

Figure 1. Location map of the study area: Gute sub-site of BARC.

Lime rating and fertilization

The amount of lime was calculated based on the exchangeable acidity, bulk density and 20 cm plow depth. It was assumed that one mole of exchangeable acidity would be neutralized by an equivalent mole of $CaCO_3$ (adopted from Kamprath, 1984).

$$LR = \frac{Ac * 0.2\ m * 10^4\ m^2 * B.D.(kg/m^3) * 1000}{2000} \qquad Eq.\ 1$$

Where: LR- Lime requirement (kg ha^{-1}), Ac- Exchangeable acidity ($cmol_{(+)}$kg soil), 0.2- plough depth, BD- Bulk density

Soil acidity ameliorant used in the experiment was calcite limestone ($CaCO_3$) obtained from Senkele limestone crushing factory, while, the N and P fertilizer sources were Urea and DAP (Di-ammonium Phosphate).

Experimental design, treatments and procedures

The experiment comprised five levels of lime (1.86, 2.79, 3.72, and 4.65 t ha^{-1}) which represented 0, 50%, 75% 100% and 125% recommended amount of lime respectively constituting a total of five treatments which was laid out in RCBD with three replications. The 110/46kg NP_2O_5 were used uniformly to all plots, the rate of which was determined based in accordance to the recommendation made based on the result of fertilizer trials conducted on different varieties of maize over years by the agronomy research case team of Bako Agricultural Research Center (BARC).

Lime was surface applied and incorporated in the soil by hand 45 days before planting in the initial year of the experiment. The test crop was a maize variety BH-660, planted at intra and inter of 75*30 cm in gross plot area of 5.1*4.5 m. The P fertilizer was band applied at planting in rows while the N fertilizer was applied in two splits where one half was applied at planting and the remaining was supplemented when the plant reached to knee height.

Net plot area of 12.8 m^2 was used for crop data collection at harvesting when 95% of the plants reached harvestable maturity. At physiological maturity, grain yield was recorded from each net plot area where the moisture content of the seed was determined for each treatment and adjusted to 12% moisture content, a standard as recommended by Biru (1979) using the formula:

$$ASW\ (g) = (RSW * 100 - M)/(100 - D)$$
(2)

Where: RSW- Adjusted seed weight, RSW- Recorded seed weight, M is the measured moisture content and D is the standard moisture content (12%) for cereal crop (Agronomic manual: Management of Field Crop, 1985).

Data analysis

Data were analyzed using SAS version 9.3 (SAS, 2004) computer software and were subjected to ANOVA to determine significant differences among factors and their interactions. Means were separated using LSD test at 0.05 significance level.

RESULTS AND DISCUSSION

Selected soil properties before sowing

According to the laboratory analytical result, the soil of the study area was sandy clay loam in texture, very strongly acidic in reaction as rated by Tekalign *et al.* (1991) and low in available P which is probably attributed to high P fixing capacity of the soil at the area (Table1). Finally, the acidic nature of the soil which can be toxic to plants and hence can depress their growth and the lower proportion of P that can potentially affect crop performance signifies that the soil needs acidity adjustment and requires external application of P fertilizer source, respectively, to sustain crop production and productivity.

Parameters	Test Result
pH H_2O (1:2.5)	4.65
Available phosphorus (ppm)	7.52
Sand (%)	48.3
Clay (%)	36.4
Silt (%)	15.4
Textural Class	Sandy clay loam
Bulk density	1.33
Exchangeable acidity (cmol$_{(+)}$kg^{-1} soil)	2.8

Table 1. Selected physicochemical properties of the soil of the experimental site before commencement of the experiment.

Soil acidity and available phosphorus dynamics in response to medium-term liming Soil pH

The laboratory analytical result showed that soil pH was affected by cropping season. The highest records for the soil pH were obtained during the third cropping season after lime application. Nevertheless, it showed a decreasing tendency in the fourth and fifth years after lime application (Figure 2).

The effect in soil reaction was observed by the application of lime where soil pH significantly increased with the lime rate after the first cropping season in which the highest value (5.61) was recorded by application of 4.65 t ha^{-1} of lime in the second harvest year. The pH attained in treatments with liming at the end of the experiment was optimum for maize growth since the most suitable pH range for optimum growth of maize is 5.5 -7.1 (Sierra *et al*., 2006).

The lowest value of pH which is below the threshold record was obtained from the plot that received the lowest amount of lime (1.86 t ha^{-1}) in the fifth cropping season, next to no lime applied plots that explains how soil pH changes over time if soils are continuously fertilized but not limed.

The application of lime alone resulted in higher soil pH in the second and third cropping years improving the soil from strongly acidic to the slightly acidic condition. The rise in pH than the initial is associated with basic cations (Ca^{2+}) and anions (CO_3^{-2}) in lime that can exchange H^+ from exchange sites to form $H_2O + CO_2$. The cations occupy the space left behind by H^+ on the exchange leading to the rise in pH (Fageria *et al*., 2007). 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 finding agrees 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 three cropping seasons which indicated that lime application had decreased soil acidity abruptly in the first year and thereafter slightly amplified over years. Although not significant, the decrease over time of pH after the third cropping year indicates that re-acidification takes place in the absence of curative lime applications. This agrees with the observation of Alemayehu *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.

Soil exchangeable acidity and Aluminum

On the whole, the liming treatments reduced soil exchangeable acidity of the experimental field in all seasons except the last harvest year that reduced the initial value (2.8 cmol$_{(+)}$kg^{-1}) (Table 1 and Figure 3) by 330% in the third cropping season. The significant temporal variation of soil exchangeable acidity is probably due to the fact that after the first season all the lime had not yet reacted with the soil. Jansen *et al*. (2009) observed a similar trend for a six-year liming experiment. This was also substantiated by observation of Athanase (2013) which suggests that it is rarely necessary to liming acid soil more frequently every 3 years. The experimental unit that received 4.65 t ha^{-1} of lime during the third cropping season was most effective in reducing exchangeable acidity that recorded 0.65 cmol$_{(+)}$kg^{-1} reducing the value by 307% compared to the control in the same year.

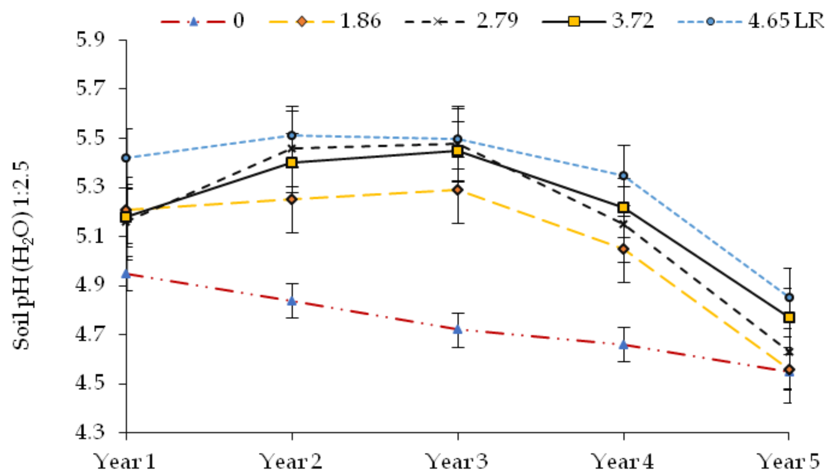

Figure 2. Soil pH as affected by the interaction of liming and cropping season (Key: LR- lime rate (tone ha^{-1}))

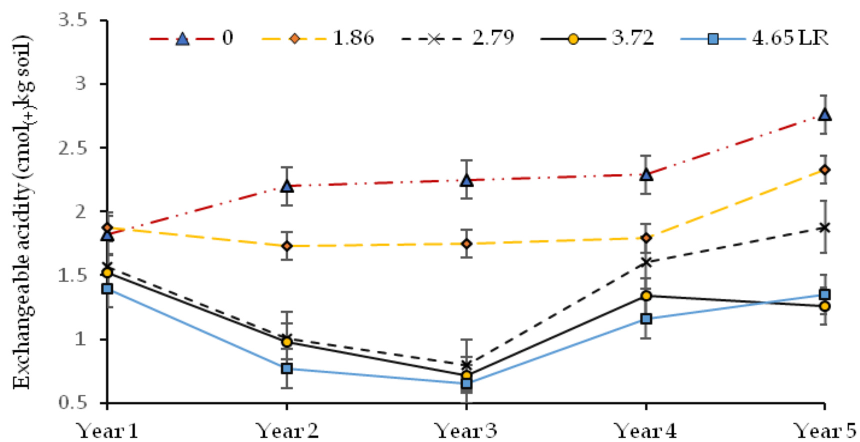

Figure 3. Soil exchangeable acidity as affected by the interaction of liming and cropping season (Key: LR- lime rate (tone ha^{-1}))

Soil available phosphorus

The findings of this study showed that amending acidic soil with lime resulted in a significant increase in available P markedly during the third and fourth cropping year in which application of the recommended rate (3.72 t/ha) of lime recorded the highest value (22.82 mg kg^{-1}) which increased the available P content of the soil by 146% over the control (Figure 4). Although soil available P significantly increased with liming, the effect is not as dramatic as for soil acidity characteristics. 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 is higher (22.85 mg kg^{-1}) than before liming (9.14 mg kg^{-1}) which clearly shows highly significant effects of soil acidity adjustment by liming on P availability. 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 conditions. Therefore, agricultural lime added to soil is a profitable soil amendment and it hydrolyzes Al and Fe ions that precipitated with P, releasing the tied-up P into the soil solution, consequently rendering the phosphate ion available for plant uptake. Liming, thus raising the pH of acidic soil generally provide more favorable environments for microbial activities and possibly results in net mineralization of soil organic P (Achalu *et al*., 2012).

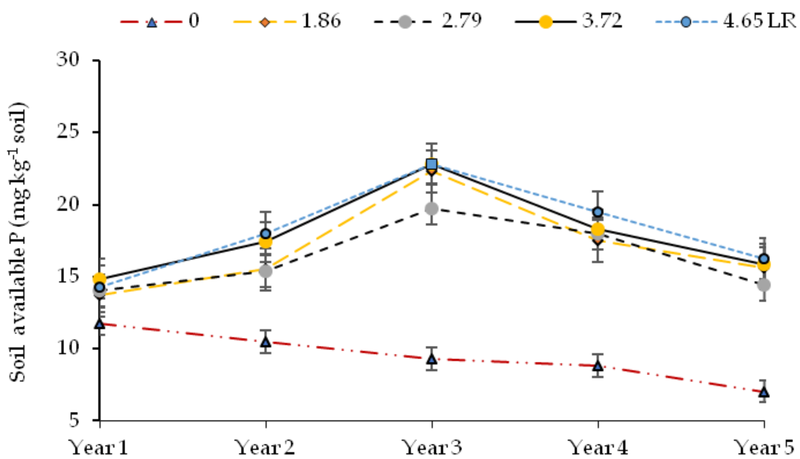

Figure 4. Soil available phosphorus as affected by liming in different cropping season (Key: LR- lime rate (tone ha^{-1}))

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 follows the 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 the 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 reduces the P sorption thus increasing its availabilities. This fact is more emphasized by Mullins (2001), Hammond *et al.* (2004) 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 the reduction of soil acidity and P fixation in soils. 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).

Combined Effects of lime and cropping season on maize grain yield

When cropping season is considered, the interaction of lime application by cropping season was significantly different for maize seed yield where the maximum mean grain yield of 7.02 tons ha^{-1} was obtained in the third cropping season improving maize productivity by 92.5% compared to the no lime treatment in the same year and 95.2% from the control plot in the first year (Figure 5). The lowest seed yield (5.11 tons ha^{-1}) was obtained from 1.86 tones ha^{-1} lime in the fifth harvesting season compared to the other lime treated plots, however, it was not significantly different from the rest of lime applied treatments except those treatments that received 3.72 and 4.65 t ha^{-1} lime. The seed yields of maize kept increasing until the third production season in which most of the values were optimal for all lime levels compared with the other cropping seasons.

The seed yield of maize declined in fourth and the fifth cropping years that showed the response of maize crop is expressively bound to time duration to lime application. Treatments without lime produced considerably the lowest seed yield in each cropping season. This tendency of yield reduction after application of lime after certain years might be attributed to declining of lime reaction through time and imbalance of N and P with other nutrients due to the altered nutrient availability to growing plants due to lime amendment (Gascho and Parker, 2001). The yield increased from year to year up to the third year and show a slight decrease from the third to the fourth but the decrease was serious after the fourth year. The result of this study agrees with the observation of Kisinyo *et al.* (2013) who recorded a four year mean grain yield increments of 0.50, 0.58, and 1.17 t ha^{-1} due to 2, 4, 6 tons ha^{-1} lime, respectively. In another field experiment where maize crop was grown at five lime rates 0, 0.5, 1.0, 2.0 and 4.0 tons ha^{-1}, Sing *et al*, (1987) described that liming at a rate of 2 t ha^{-1} maintained high maize yield for three years after application at Kontagora and Yandev. A Similar result was obtained by Abay (2011) that indicated lime with NP application has a residual effect up to the third cropping season at Areka that illustrated longer years of production after liming resulted in re acidification of the soil which necessitates re-liming the soil.

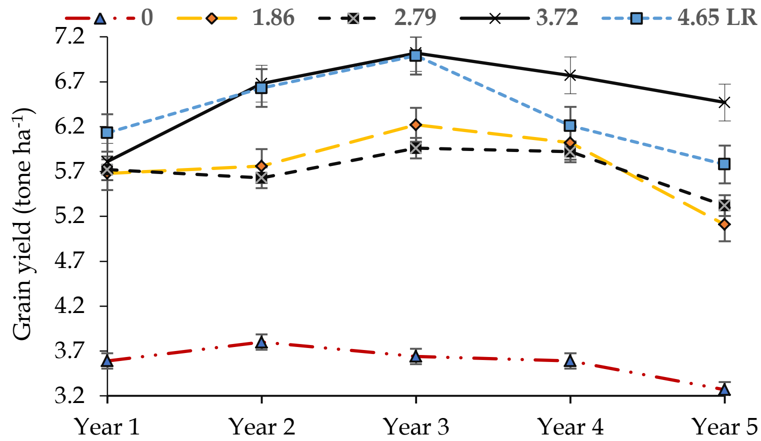

Figure 5. Grain yield of maize as affected by lime application in cropping season at Gute (2012-2016) (Key: LR- lime rate (tone ha^{-1}))

CONCLUSION

The result of the study indicates that, liming increased maize grain yield, reduced soil acidity, and improved available P. The soil test result showed that all measured soil parameters were affected by liming in which the highest record for these properties were obtained during the third cropping season after lime application. Indeed, the reclaiming power of lime shown decreasing tendency during the fourth, and fifth years after lime application even though the soil acidity level didn't revert to its horrible past. This 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 maize production in such acidic belt areas of the country.

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