Effect of Lime Application Methods on Selected Soil Chemical Properties and Yield of Maize (*Zea Mays L.*) in Acidic Nitisols of Mecha District, Amhara Region, Ethiopia

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Abstract

Soil acidity is the major soil chemical constraints that limit agricultural productivity in the highland of Ethiopia receiving high rainfall amount. This study was conducted to evaluate the effect of different lime application methods on selected soil chemical properties and yield of maize (Zea mays L.) on acidic Nitisols of Mecha district, Amhara Region, Ethiopia in the 2018 cropping season. The experiment had 10 treatments (0, 0.06, 0.12, 0.18, 1, 2, 3.5, 4, 7, and 14 tons ha^{-1} lime) which were calculated in 3 different lime rate determination methods and applied through 3 different methods (spot, drill, and broadcast). The experiment was designed in RCBD with four replications. N 180 and P_2O_5 138 kg ha^{-1} were used, respectively. A full dose of P and lime as a treatment were applied at planting. Whereas N was applied in split, 1/2 at planting, and 1/2 at knee height stage. One composite soil sample before planting and soil samples from each experimental unit after harvesting were taken to analyze the required parameters with their appropriate procedure. The drill lime application method showed better efficiency with having more than 200% cost reduction advantage comparative to the broadcast method to ameliorate the same level of soil acidity. Grain and above-ground biomass of maize yields showed a significant difference among treatments. The application of 3.5 tons lime ha^{-1} in the drilling method is recommendable and best to ameliorate soil acidity. But, from an economic point of view, the application of 0.12 tons lime ha^{-1} in the micro-dosing method is acceptable due to low variable cost.

Keywords: *Exchangeable acidity, Lime, maize, pH- buffer, pH-H_2O*

Introduction

Agriculture in Ethiopia has long been a priority and focus of national policy, such as Agricultural Development Led Industrialization (ADLI) and various large-scale programs, like Plan for Accelerated and Sustained Development to End Poverty (PASDEP). Close to

more than 85% of the population, generates over 46% of GDP and 80% of export earnings, and has a significant role to play in improving food security (Alemayehu Seyum, 2008). Soil supports plant growth and is vital to humanity. It provides nutrients such as nitrogen, phosphorous, potassium, calcium, magnesium, sulfur, and many other trace elements that support biomass production. Also, it gives service as an anchor for plant roots and as a water holding tank for needed moisture and it provides a hospitable place for a plant to take root. Some of the soil properties like texture, aggregate size, porosity, aeration (permeability), and water holding capacity affecting plant growth (FAO and ITPS, 2015).

Maize is one of the three most important cereals with wheat and rice for food security at the global level and very important in the diets of the poor in Africa and Latin America (Bekele Shiferaw *et al.*, 2011) and (FAOSTAT, 2010). In many developed countries and the emerging economies of Asia and Latin America maize is increasingly being used as an essential ingredient in the formulation of livestock feed (Bekele Shiferaw *et al.*, 2011). In Ethiopia maize is the most widely cultivated cereal crop with 16% area coverage, 26% production potential, and 6.5 million tons of production (CSA, 2014). The estimated average yields of maize for smallholder farmers in Ethiopia is about 3.2 tons ha^{-1} (CSA, 2014; Tsedeke Abate *et al.*, 2015), which is much lower than the yield recorded under experimental plots of 5 to 6 tons ha^{-1} (Dagne Wegary *et al*., 2008). To solve soil fertility problems and maximizing maize yield, different research activities have been undertaken in Ethiopia using various fertilizer sources (Birhan Abdulkadir *et al*., 2017).

Acid soils are toxic for plants during their production period as a result of nutritional disorders, deficiencies or unavailability of essential nutrients such as Ca, Mg, P, and Mo, and toxicity of Al, Mn, and H activity (Jayasundara *et al.*, 1998). In acid soils, excess Al primarily injures the root apex and inhibits root elongation. This poor root growth again leads to reduced water and nutrient uptake and consequently crops grown on acid soils faced poor nutrients and water availability with the net effect of reducing growth and yield of crops (Wassie Haile and Shiferaw Boke, 2014). Occurrences of an increasing trend of soil acidity in arable and abandoned lands are attributed due to the high amount of rainfall, intensive cultivation, and continuous use of acid-forming inorganic fertilizers (Abdenna Deressa *et al.*, 2007). As Taye Belachew (2007) reported, soil acidity in Ethiopia is expanding both in scope and magnitude and becoming severely limiting crop production.

To solve such type of problems application of lime properly is the fundamental action as stated by Adane Buni (2014) which was reported as soil pH increase from 5.03 to 6.72 by applying 3.75 tons ha^{-1} lime and similarly increased CEC and available P of the soil. But, inversely EA and most micronutrient availabilities significantly decreased due to liming which is supported by (Goedert *et al.*, 1997; Kebede Dinkecha and Dereje Tsegaye, 2017) findings. Therefore, the interest of this study was to investigate the effect of different lime application methods determined through different rate determination methods on selected soil chemical properties and maize (*Zea mays L.*) yield.

Materials and Methods

Description of the Study Area

The study was conducted at Kudemie *kebele* (lowest administrative unit of Ethiopia), Mecha district that is approximately 525 km far away from Addis Ababa in the north direction. Specifically, the study site is located at 11° 23' 33.49" Northing and 37° 06' 25.23" Easting at 1972 meters a.s.l (Figure 1). Based on CSA (2015) data, Mecha district had a total population size of 222,373. From the total population size, 201,147 people live in the rural *kebeles* and the remaining 21,226 people live in Merawie town.

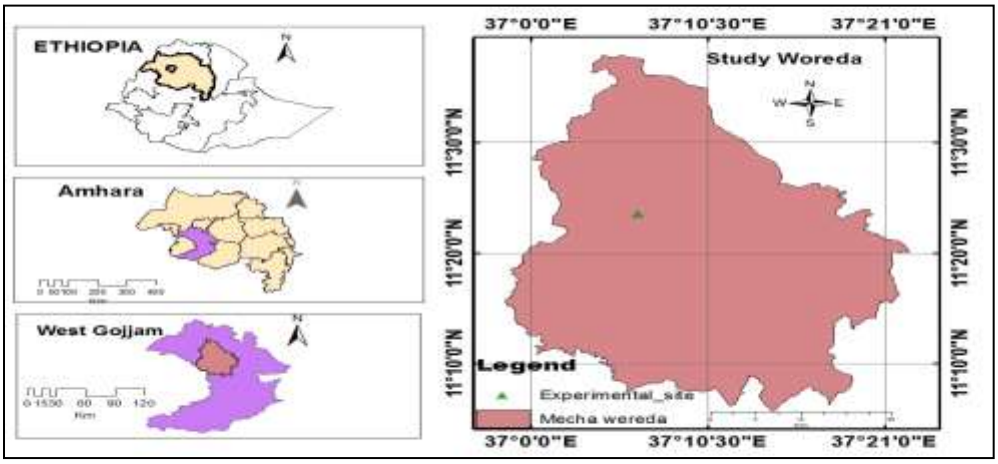

Figure 1. Location of the study area

Topography, soil type, and climate

The study area has dominantly 70% flat topographic coverage. From the total area of the district, 13% is undulated and the remaining 8% and 4% of the area are covered by mountainous and valley topographies, respectively. The annual mean rainfall amount of the district is 1572 mm and the mean temperature is 25°C (Mekonnen Getahun, 2015). According to Ethiopian traditional agro-ecological classification, the study district is classified under *Weyina Dega* (1800 to 2400 m.a.s.l) (Mekonnen Getahun, 2015). Specifically, the mean annual rainfall and temperature of the experimental site during the cropping season were 314.9 mm and 19.3°C, respectively. From the total area coverage of the district, 5,927 ha which is 4% is included under the Koga irrigation command area (Eyasu Elias, 2016).

Farming system and land use of the area

The dominant farming system of the district is a mixed farming system that is livestock with crop production and rainfall dependent where the average productivity has been substantially decreased due to the major co2 raitis lieof y nd a(e)4,( )479(a)4(nd)59[(c)4(rop)464(pe)42

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unpublished). The amount of lime added in terms of time and ways of application was based on the treatment setup indicated in Table 1.

Table 1. Treatment setup of the conducted experiment

No.	Treatments	Application methods
1	Control	Treatment without lime
2	0.06 ton ha^{-1}	Micro-dosing in a spot near the seed hill
3	0.12 ton ha^{-1}	Micro-dosing in a spot near the seed hill
4	0.18 ton ha^{-1}	Micro-dosing in a spot near the seed hill
5	1 ton ha^{-1}	¼ FDEA = in drilling along the rows
6	2 ton ha^{-1}	½ FDEA = in broadcasting
7	3.5 ton ha^{-1}	¼ FDB = in drilling along the rows
8	4 ton ha^{-1}	FDEA = in broadcasting
9	7 ton ha^{-1}	½ FDB = in broadcasting
10	14 ton ha^{-1}	FDB = in broadcasting

Note: FDEA=Full dose based on exchangeable acidity, FDB= Full dose based on pH-buffer

Lime Rate Determination

The amount of lime rates used was determined through 3 mechanisms. The first 4 rates (0, 0.06, 0.12, and 0.18 tons ha^{-1}) were added directly as micro-dosing levels. The other 3 rates (1, 2, and 4 tons ha^{-1}) were calculated based on the EA method which was formulated by (Birhanu Agumas *et al.,* 2016) as indicated below in (Eq-1) and the remaining 3 rates (3.5, 7, and 14 tons ha^{-1}) were calculated based on SMP-pH-buffer to attained 6.5 target pH value from the initial result based on SMP-pH-buffer lime amount determination stated by Van Reeuwijk (1992).

LR $CaCO_3$ (kg ha^{-1}) = (Eq-1)

Where: EA=2.54 $Cmol_+$ kg^{-1}, Bulk density=1.41 Mg/m^3 taken from pre-liming soil analysis result.

Soil Sampling, Preparation and Analysis Methods

One composite soil sample before planting and from each experimental unit after harvesting was taken in the depth of (0-15) cm. Soil pH-H_2O, pH buffer, EA, CEC, OC, AP, TN, and all exchangeable cations were analyzed. The above parameters were analyzed in Adet soil laboratory following their appropriate procedural methods. Based on the above soil parameters, BS and AS percentage values were also calculated through the formulas stated below.

BS = ; AS = -2)

Other Agronomic Data Collected: Important agronomic data like plant height, ear length, ear diameter, 1000 grain weight, harvest index (HI), and all biological yields (grain + straw) were taken.

Cultural Practice: Weeding and other necessary agronomic practices were implemented mechanically. Agro-lambarcin pest controlling chemical was used at the time of vegetative to control the American worm (which is also called Temich in Amharic).

Statistical Tools Used: SAS software version 9.0 was used to analyze all collected agronomic data. LSD was used for mean separation comparison. The economic analysis was done following the methodology of CIMMYT (1988).

Results and Discussion

Effect of Lime on Selected Soil Chemical Properties

Soil pH-H_2O and pH-buffer

As shown in Table 2 and 3, pH-H_2O raised from 4.85 to 6.21 which is from very strongly acidic to slightly acidic pH range Murphy (1968) and Tekalign Tadese (1991) through the application of 3.5 tons ha^{-1} lime with drilling application. This value is the maximum value scored in the experiment which is suitable for maize production (Ndubuisi and Deborah, 2010). But, a minimum (4.87) value was recorded on treatment 2 which received 0.06 tons ha^{-1} lime through the spot application method. Comparing the 3 lime application methods, maximum pH-H_2O values were obtained on the drill lime application method. In general, pH-H_2O of the soil in the study site showed an increasing trend with a significant difference ($p<0.001$) among treatments due to an increase in the amount of lime applied.

This result is agreed with (Achalu Chimdi *et al.,* 2012 and Getachew Alemu *et al.,* 2017) findings which were stated as soil pH was sharply increased by liming. Like that of pH-H_2O, pH buffer had a significant difference ($p<0.001$) among treatments with an increasing trend due to the increasing amount of lime applied in the experimental area. Similarly, minimum and maximum pH buffer values were observed on points where the minimum and maximum pH-H_2O values were recorded in magnitudes of 4.98 and 6.03, respectively (Table 3).

Table 2. Soil chemical properties before application of lime

Parameters										
pH (H_2O)	pH (Buffer)	OC (%)	CEC ($Cmol_+kg^{-1}$)	AP ($mgkg^{-1}$)	TN (%)	EA ($Cmol_+kg^{-1}$)	Exchangeable bases ($Cmol_+ kg^{-1}$)			
							Ca	Mg	K	Na
4.85	5.24	2.19	19.95	18.03	0.17	2.54	9.8	2.68	1.14	0.31

Note: OC=organic carbon, TN=total nitrogen, CEC=cation exchangeable capacity

Based on Tekalign Tadese (1991) nutrient rating level both pre-planting and post-harvest soil sample OC and TN% values were grouped under medium levels as shown in Tables 2 and 3. But, based on Murphy (1968) and Ethiosis (2016) the recorded TN% values could be grouped from medium to high (0.10-0.15%) and low to optimum (0.15-0.25/0.3%), respectively. As reported by Kebede Dinkecha and Dereje Tsegaye (2017); Jafer Dawid and Gebresilassie Hailu (2017) and Mesfin Kassa *et al*. (2014), OC and TN% of the soil in thi
show any significant difference among treatments through the application of different lime amounts in different application methods (Table 3). This indicated that OC and TN are not giving quick responses for liming within a short time.

Cation exchange capacity (CEC)

Based on the analysis of variance (ANOVA) result, soil CEC values showed a significant difference ($p<0.05$) between treatment 3 and 7 which received 0.12 and 3.5 tons ha^{-1} lime and applied in spot and drilling application methods with the magnitudes of 21.85 and 25.41 $Cmol_+ kg^{-1}$, respectively. These values were minimum and maximum values in the study site, respectively. Based on Landon (1991); Hazelton and Murphy (2007) nutrient rating level, all recorded CEC values for post-harvested and before liming soil samples were grouped under moderate ranges. As a general trend, CEC values observed in the experiment slightly increased with increasing of the amount of lime applied up to treatment 7 which received 3.5 tons ha^{-1} lime applied through drilling system that agreed with the finding reported by Achalu Chimdi *et al.* (2012) who stated as numerically the mean values of soil exchangeable Ca^{2+} and CEC of each land-use type showed increments with the increase of applied lime rates and Adane Buni (2014) who also stated as all lime levels resulted in a significant increment to soil CEC values over the control plots.

Available phosphorus (AP)

The recorded AP values for all treatments were above the critical P concentration (>11.6 mg kg^{-1}) which was reported by Yihenew G.Selassie *et al.* (2003). As shown in Table 3, AP values among the treatments showed a significant difference ($p<0.001$) due to the different amounts of lime application through different application methods. In this study, AP showed a decreasing trend with an increasing amount of lime applied, which is contrary to the findings reported by several authors Adane Buni (2014), Dessalegn Tamene *et al.* (2017), Getachew Alemu *et al.* (2017), and Kebede Dinkecha and Dereje Tsegaye (2017). But, this result agreed with the finding reported by Haynes (1982). According to Haynes (1982) at high soil pH and low Al^{3+} concentration values, the precipitation of insoluble calcium phosphates has the power to reduce P availability. Therefore, in this study context, the laboratory soil analysis results showed zero exchangeable Al readings and this may be caused

ha^{-1}). According to Olsen *et al.* (1954), the recorded AP values for before and after liming samples were attained at a higher level. Minimum and maximum values were observed on the control treatment (17.17 mg kg^{-1}) and micro-dosing level (0.06 tons ha^{-1} lime) (37.80 mg kg^{-1}) (Table 3).

Exchangeable acidity (EA)

As the soil laboratory analysis result showed, exchangeable Al^{3+} for all samples was in a trace amount in the study area. Therefore, the source of soil acidity was only H^+ concentration. Besides this, EA on the experimental site showed a highly significant difference ($p<0.01$) among treatments (Table 3). As indicated in Table 3 EA showed a decreasing trend with the reverse of the amount of lime applied. This is usually true and agreed with many findings such as Achalu Chimdi *et al.* (2012); Adane Buni (2014); Dessalegn Tamene *et al.* (2017) and Getachew Alemu *et al.* (2017) which were stated as EA reduced due to an increase of the applied lime.

Table 3. Soil pH-H2O, pH-buffer, OC, CEC, AP, and EA values for post-harvested soil samples

Treatments	Parameters						
	pH (H_2O)	pH (buffer)	OC (%)	TN (%)	CEC ($Cmol_+kg^{-1}$)	AP (mg kg^{-1})	EA ($Cmol_+kg^{-1}$)
Control (no lime)	5.11^{de}	5.14^{de}	1.94	0.166	22.81^{ab}	17.17^{d}	1.939^{a}
0.060 ton ha^{-1}	4.87^{e}	4.98^{e}	2.01	0.149	22.89^{ab}	37.80^{a}	2.020^{a}
0.120 ton ha^{-1}	4.95^{e}	5.01^{e}	2.07	0.168	21.85^{b}	33.56^{b}	1.788^{a}
0.180 ton ha^{-1}	5.27^{de}	5.07^{de}	1.95	0.168	23.47^{ab}	34.47^{ab}	0.936^{b}
1 ton ha^{-1}	5.52^{cd}	5.75^{ab}	1.89	0.139	24.53^{ab}	31.86^{bc}	0.480^{bc}
2 ton ha^{-1}	5.28^{de}	5.33^{dc}	2.09	0.161	24.82^{ab}	29.12^{c}	0.460^{bc}
3.5 ton ha^{-1}	6.21^{a}	6.03^{a}	1.95	0.162	25.41^{a}	31.34^{bc}	0.070^{c}
4 ton ha^{-1}	5.49^{cd}	5.65^{b}	2.09	0.144	23.38^{ab}	20.01^{d}	0.116^{c}
7 ton ha^{-1}	5.77^{bc}	5.55^{bc}	2.00	0.163	23.22^{ab}	18.93^{d}	0.288^{c}
14 ton ha^{-1}	6.17^{ab}	6.01^{a}	1.95	0.142	24.50^{ab}	20.90^{d}	0.048^{c}
Mean	5.46	5.45	1.99	0.156	23.69	27.52	.814
P	**	**	Ns	Ns	*	**	**
CV (%)	5.55	3.97	10.49	15.05	10.24	10.53	50.31

In between this, minimum and maximum EA values were recorded on treatments that received 14 tons ha^{-1} lime (applied in broadcasting) and 0.06 tons ha^{-1} lime (applied in the spot) with magnitudes of 0.048 and 2.020 $Cmol^{+}kg^{-1}$ of soil, respectively. Control treatment showed a clear significant difference from treatment 4 to 10 (Table 3).

Exchangeable base values

As shown in Table 4, exchangeable Ca and Mg showed a highly significant difference among treatments ($p<0.001$) whereas, exchangeable K and Na showed a significant difference among treatments ($p<0.015$) and ($p<0.02$), respectively due to liming. It is apparent that the applied lime showed a positive response for all exchangeable bases which is agreed with many findings reported by Hirpa Legesse *et al.* (2013); Holland *et al.* (2017); Jafer Dawid and Gebresilassie Hailu (2017); Achalu Chimdi *et al.* (2012); Adane Buni (2014) and Getachew Alemu *et al.* (2017) which were collectively stated as treating of acid soils with lime showed an increasing trend of exchangeable bases and decrease micronutrients and EA in the soil solutions exchange complex and helped to increase of plant nutrient availabilities due to enhancing of soil pH value.

All minimum and maximum exchangeable base values were recorded on treatment 2 and 7 that received 0.06 and 3.5 tons ha^{-1} lime through spot and drill lime application methods, respectively in exception of maximum exchangeable Mg. This showed that drill lime application is more efficient for the amendment of the base cation in acid soil than the broadcast application methods that agreed with the finding of (Birhanu Agumas *et al.*, 2016). Based on FAO (2006) nutrient rating, recorded exchangeable Ca, Mg, K, and Na grouped under high, medium to high, high to very high, and medium rating levels, respectively.

Base and acid saturation percentages

The amount of lime applied in the study area showed a positive and significant difference with the increasing trend on soil base saturation percentage among treatments. In opposite, acid saturation percentage showed a decreasing trend when the amount of lime applied increased which is in agreement with findings of Achalu Chimdi *et al.* (2012); Adane Buni (2014), and Getachew Alemu *et al.* (2017) (Table 4). Based on Hazelton and Murphy (2007) all the observed base saturation percentage values are grouped at a high rating level which is from 60-80%. Acid saturation percentage reduced from 8.69% in the 0 ton ha^{-1} to 0.19% at 14 tons ha^{-1} lime application.

Table 4. Soil exchangeable base cations, BS, and AS for post-harvested samples

Treatment	Parameters					
	Ca	Mg	K	Na	BS (%)	AS (%)
Control (no lime)	10.73^{de}	2.90^{bc}	1.38^{dc}	0.48^{bc}	69.03^{ab}	8.69^{a}
0.060 ton ha^{-1}	10.18^{e}	2.30^{c}	1.20^{d}	0.44^{c}	62.06^{b}	8.80^{a}
0.120 ton ha^{-1}	10.85^{cde}	2.68^{bc}	1.43^{bcd}	0.45^{c}	71.61^{ab}	8.01^{a}
0.180 ton ha^{-1}	11.38^{bcd}	3.03^{b}	1.48^{abc}	0.44^{c}	70.43^{ab}	3.81^{b}
1 ton ha^{-1}	12.30^{ab}	3.05^{b}	1.63^{ab}	0.61^{ab}	72.37^{ab}	1.92^{bc}
2 ton ha^{-1}	11.85^{abcd}	3.05^{b}	1.53^{abc}	0.58^{abc}	68.69^{ab}	1.84^{bc}
3.5 ton ha^{-1}	12.95^{a}	3.98^{a}	1.70^{a}	0.65^{a}	75.85^{ab}	0.27^{c}
4 ton ha^{-1}	11.75^{bcd}	3.15^{b}	1.42^{bcd}	0.56^{abc}	74.64^{ab}	0.49^{c}
7 ton ha^{-1}	12.03^{abc}	3.88^{a}	1.52^{abc}	0.47^{bc}	78.71^{a}	1.25^{c}
14 ton ha^{-1}	12.50^{ab}	4.30^{a}	1.52^{abc}	0.64^{a}	78.19^{a}	0.19^{c}
Mean	11.65	3.23	1.48	0.53	72.16	3.53
P	**	**	*	*	*	**
CV (%)	7.02	14.13	10.96	19.29	13.58	46.65

Recommended Lime (LR) Equations Based on Important Soil Acidity Indices

As shown in Figures 2 and 3, the LR decreased when soil pH buffer and pH-H_2O increased for both drilling and broadcast lime application methods. However, LR increases when the EA of soil increased for the same methods of lime application (Figure 4) which is agreed with the findings reported by Shoemaker *et al.* (1961) and Van Reeuwijk (1992).

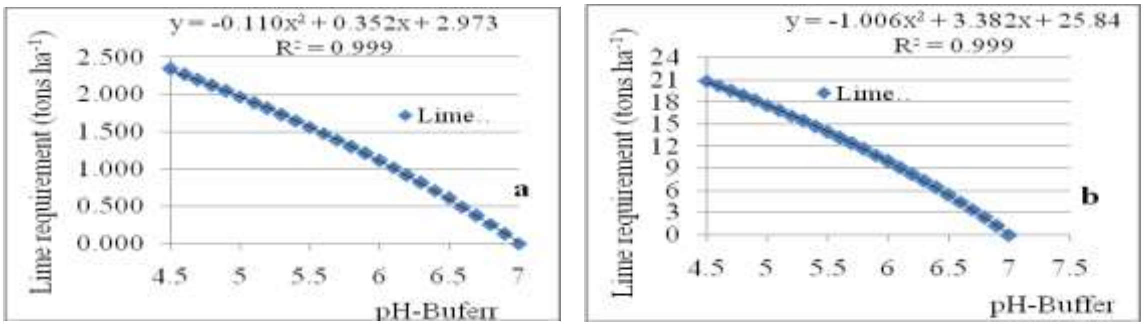

Figure 2. LR equations for drill (a) and broadcast (b) application methods using pH-buffer index

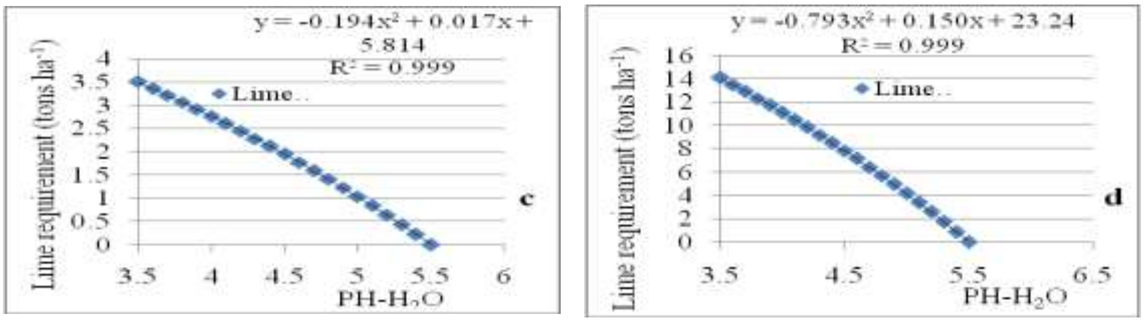

Figure 3. LR equations for drill (c) and broadcast (d) application methods using pH-H_2O index

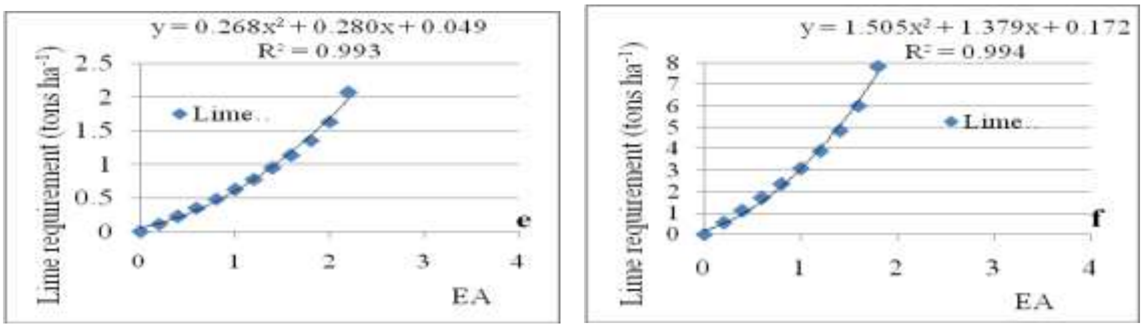

Figure 4. LR equations for drill (e) and broadcast (f) application methods using EA index.

Based on the deriving equations indicated in Table 5, calculated LR based on pH-buffer, pH-H_2O, and EA ranged from 0.13 to 2.34, 0.22 to 3.50 and 0.11 to 2.07 tons ha^{-1} for drilling and 1.18 to 20.83, 0.90-14.11 and 0.53 to 7.86 tons ha^{-1} for the broadcast method, respectively. Based on these readings, the amount of lime required through drilling is much lower compared to the broadcast application method to ameliorate the same level of acidity within the same soil acidity indices and which is agreed with the finding reported by Birhanu Agumas *et al*. (2016).

Table 5. LR equations developed from soil acidity indices

Application methods	Acidity index	Index unit	LR equations	R^2
Broadcast	PH- buffer	----------	$Y = -1.0063x^2 + 3.383x + 25.845$	0.9998
	PH-H2O	----------	$Y = -0.7935x^2 + 0.151x + 23.249$	0.9999
	EA	$Cmol_+kg^{-1}$	$Y = 1.5051x^2 + 1.3794x + 0.1728$	0.9946
Drilling	PH- buffer	----------	$Y = -0.1106x^2 + 0.353x + 2.9735$	0.9998
	PH-H2O	----------	$Y = -0.1947x^2 + 0.017x + 5.8147$	0.9999
	EA	$Cmol_+kg^{-1}$	$Y = 0.2681x^2 + 0.280x + 0.0497$	0.9939

Note: Y=Lime rate to be applied, x=Soil acidity index value

Effect of Lime on Yield and Yield Components of Maize

As shown in Table 6, the applied lime didn't show any significant difference in maize plant height, ear length, ear diameter, thousand seed weight, harvest index, and straw yield among treatments. Although the experiment didn't show any significant difference in the above-listed yield components, the maximum values of each component were recorded on treatments that received a high amount of lime which is supported by Gitari *et al.* (2015) and Opala (2017) findings. But, maize grain and above-ground biomass yields showed a significant difference treatments. Generally, both grain and above-ground biomass yields in the experiment showed an increasing trend due to liming which is supported by findings reported by Komljenovic *et al.* (2015) and Oloo (2016). As Agrama (1996) stated, the trend of grain yield is parallel with trends shown on yield components of maize.

Table 6. Plant height, ear length, ear diameter, harvest index, thousand seed weight, grain yield, straw yield, and above-ground biomass yield

Treatment	PH (cm)	EL (cm)	EDI (cm)	HI (%)	TSW (g)	GY(kg ha^{-1})	STY (kg ha^{-1})	AGBM (kg ha^{-1})
Control (no lime)	201.05	15.40	4.54	37.87	397.75	6479.1^{b}	8526.5	15004.6^{b}
0.060 ton ha^{-1}	202.00	15.48	4.63	38.44	399.75	6628.3^{b}	9101.4	15721.8^{ab}
0.120 ton ha^{-1}	200.15	16.35	4.61	38.91	400.75	6840.3^{ab}	9131.9	15972.2^{ab}
0.180 ton ha^{-1}	200.00	16.03	4.66	39.84	401.50	6621.8^{b}	9311.9	15930.6^{ab}
1 ton ha^{-1}	201.00	16.60	4.73	40.22	407.00	6862.4^{ab}	9466.5	16333.3^{ab}
2 ton ha^{-1}	201.80	16.65	4.63	39.86	406.50	6871.4^{ab}	9748.7	16620.4^{ab}
3.5 ton ha^{-1}	202.60	16.40	4.65	39.83	405.25	6964.3^{ab}	9420.4	16375.0^{ab}
4 ton ha^{-1}	201.80	17.30	4.62	41.72	408.75	7719.1^{a}	10467.0	18180.6^{a}
7 ton ha^{-1}	206.90	16.53	4.69	39.26	410.25	6988.0^{ab}	9510.1	16504.6^{ab}
14 ton ha^{-1}	205.93	16.20	4.74	40.48	404.50	7106.3^{ab}	9807.2	16912.0^{ab}
Mean	202.32	16.29	4.65	39.64	404.20	6908.01	9449.2	16355.5
P	Ns	Ns	Ns	Ns	Ns	*	Ns	*
CV (%)	6.31	11.17	5.51	9.52	8.44	10.9	15.2	10.6

Note: FDB=full dose of the buffer, FDEA=full dose of exchangeable acidity, PH=plant height, EL=Ear length, ED=Ear diameter, HI=harvest index, TSW=Thousand seed weight, LSD=least significant difference, CV=Coefficient of variation, SE±=Standard error of the mean, Ns=non-significance of F-test at alpha 0.05 level.

Economic Analysis

MRR was calculated after ordering the treatment TVC values in increasing order and excluding dominated treatments. According to CIMMYT (1988), when all the comparable treatments showed more than 100% MRR value in the experiment, treatment having the highest NB value can be taken as economically profitable and recommendable to the users. Based on CIMMYT (1988) rule, the treatment that received 0.120 tons ha^{-1} lime and applied through the spot application method gave >100% MRR value and the highest NB (60,897.6 Birr) which can be taken as an economically acceptable and recommendable lime rate for users.

Conclusions and Recommendations

In conclusion, the drill lime application method gave a better response to improve selected soil chemical properties significantly. This application method showed high efficiency to ameliorate soil acidity with more than 200% lime cost reduction advantage comparative to the broadcast application method. Application of different lime rates affected maize grain yield and slightly affected maize yield components. From an economic point of view, the use of 0.12 tons ha^{-1} lime in the micro-dosing application method had an acceptable economic profit. Therefore, the following points are suggested as recommendations. For farmers who afford to apply much amount of lime, it is recommended to apply 3.5 tons ha^{-1} lime through the drill lime application method to improve the basic soil chemical properties in a short time for residual effect. However, for farmers who are unable to apply the above-recommended lime rate, it is possible to use the micro-dose rate (0.12 tons ha^{-1}) to get an efficient and acceptable economic profit. Moreover, further studies are required on replicated sites for consecutive years to get more reliable and granted results.

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