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Low Amount of Calcium Oxide Application on Soil Chemical Properties and Crop Performance in Acid Soil Prone Areas of Ethiopia

Tolossa Ameyu*, Ewunetu Teshale, Bikila Takala and Adugna Bayata

Ethiopian Institute of Agricultural Research; Jimma Research Center P.O Box 192, Jimma, Ethiopia

**Corresponding author*

Abstract

Application of small amounts of lime significantly increased maize and soybean grain yield suggesting that micro-dosing has the potential to increase maize production on acid soil of Ethiopia. Liming of acidic soil on smallholder farms is one of the major challenges to enhance crop yields in south western Ethiopia. This may be attributed to the additional investment cost for liming. The study was carried out to investigate the effects of micro-dosing of CaO lime on selected soil chemical properties and yield and yield components of maize and soybean at Jimma and Mettu 2012-2013. A study was conducted during 2011/12-12/13 season at Jimma and Mettu to evaluate the response of reduced lime application rates of 0%, 6.25%, 25% and 33.3% ha^{-1} applied as micro-dosing. A uniform fertilizer application was made on all plots. Partial budget analysis was undertaken. Results showed that the 'no lime' control (1269 and 3663.6 kg ha^{-1}) gave the lowest grain yield for soybean and maize respectively. The highest yields of 1913 and 6268.9 kg ha-1 were observed from the 33.3% ha^{-1} application for soybean and maize respectively. The results consistently demonstrate that 6.25% ha^{-1} of quick lime as micro dose resulted in better maize growth and yield compared to no lime and 12.5% ha^{-1} treatment rate. The results suggest potential to reduce application rates and increase yield of maize through micro-dosing of agricultural lime and provide a solid basis for wider evaluation of the concepts for subsequent rolling out to famers and it is recommended that it should be evaluated along with other integrated soil management options that are proven to ameliorate soil acidity and improve yields.

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Keywords

Soil acidity, Micro-Dosing application, Maize and Soybean.

Introduction

Agricultural production in the high rainfall areas is constrained by soil acidity and soil fertility depletion (Kanyanjua *et al.*, 2002). The yields of maize, which is the staple food in these areas, are very low, and also yields of soybean is very low averaging less than 13kg ha^{-1} against a potential of 35 kg ha^{-1}. To mitigate these constraints, many soil fertility management technologies have been attempted. These ranges from use of inorganic fertilizers to use of organic inputs (Sanginga & Woomer, 2009; Okalebo *et al.*, 2006) but these approaches have several drawbacks which have hindered their adoption by smallholder farmers in Ethiopia. In particular, use of organic inputs is labor intensive; they are of often low in nutrient content and not available in sufficient quantities on smallholder farms. Inorganic fertilizers, on the other hand, are expensive and most smallholder farmers cannot afford them (Sanchez *et al.*, 1997). However, use of fertilizers remains the key to increasing food productivity in Africa (Quinones *et al.,* 1997). There has been therefore growing interest to find alternative interventions that promote efficient and sustainable use of fertilizer tailored to smallholder farmers' socio-economic conditions (Nziguheba, 2007).

There is potential to reduce the lime requirements and increase yield through micro dosing of lime application (The *et al.*, 2012; Kisinyo *et al.*, 2015; One Acre Fund, 2016), including application by point placement or dollop method (One Acre Fund, 2016). Micro-dosing technology was developed and promoted by ICRISAT and partner institutions Over a decade ago to promote the use of fertilizers in the semi-arid tropics (Chianu and Tsujii, 2005; Hayashi *et al.,* 2008; Twomlow *et al.,* 2010). Therefore there is need to test the technology on high acid soils prone areas of that limit crop production thereby threaten the livelihood of small scale farmers. For example, while the recommended N and P fertilizer rates for maize production in western Kenya are 75 kg N and 26 kg P ha^{-1} (Kenya Agricultural Research Institute (KARI), 1994), other research however suggests that farmers can increase their average yield by 50-100% by applying as little as 10 kg N ha^{-1} (Twomlow *et al.,* 2010) therefore improving the prospects of adopting the use of fertilizers. In addition, fertilizer use efficiency could be improved by liming the acid soils to eliminate Al toxicity (Kisinyo *et al.*, 2014), thereby resulting in a reduction in the amount of fertilizer required to achieve a target yield. Even though micro-dosing has the above advantages its limitations are frequent application and it applied during the planting time. Adequate amounts of liming do long last period of time (Fageria and Baligar, 2008). According to the finding of Endalkachew Fekad *et al.,* (2017) liming of acidic soil before 40 to 60 days to planting would allow decomposition and chemical reaction of lime. The studies were conducted to compare the effectiveness of applying reduced rates of agricultural lime on maize and soybean growth and yield.

Materials and Methods

The study area, Experimental design, Treatment and procedure

Field experiments were conducted with CaO using soybean and maize as a test crops in two sets separately for each from 2011/12 – 2012/13 cropping seasons in Ilubabor zones at Hurumu research sub-station for maize and at melko for soybean. In each season maize and soybean crops were planted at a time in different sets in the same block. CaO were applied yearly for each treatment accordingly. Prior to the commencement of the trial, composite soil samples were collected from the upper 20 cm depth and analyzed for soil pH and exchangeable acidity. In this regard, initial exchangeable acidity of Hurumu and Jimma site was 1.6and 2.12 Cmol kg^{-1}respectively. In this study, five levels of CaO (0.0%, 6.5%, 12.5%, 25% and 33%calculated based on neutralizing value of liming materials) were used as a treatment.

Maize variety BH 661 and Soybean variety Clark 63K were used as test crops. Maize seeds were sown in 80 cm x 50 cm with two seeds per hill whereas soybean seeds were sown in 60 cm x 5 cm spacing. Randomized complete block design with three replications were used. The amount of lime that was applied at each level was calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil bulk density and exchangeable Al^{+3} and H^{+} of each site assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of CaCO3 as described in equation below

$$LR\ (CaCO3\ kg/ha) = \frac{EA\ (Cmol/kg\ of\ soil) * 0.15m * 10^4 m^2 * BD\ (Mg\ m^3) * 1000}{2000}$$

Where LR = Lime requirement of the soil based on exchangeable acidity and EA = Exchangeable acidity

The recommended lime (CaO) rate of the area was determined as micro dose. The 6.5%, 12.5%, 25% and 33% of the recommended lime rate was applied in micro dosing application uniformly by hand in row and mixed in the top 15 cm soil layer at a time of planting according to the arranged treatments. Recommended rate of N, 46kg N ha^{-1} and 92kg N ha^{-1} were uniformly applied for soybean and maize, respectively. However, 20kg P ha-1 was uniformly applied for all treatments and for both test crops. Application of urea was made in two splits, half at sowing and half at knee height; while the entire rate of phosphorus was applied at sowing by band. Data collected were subjected to analysis of variance using SAS software packages and mean separation was done using LSD (Gomez and Gomez, 1984) at 5% probability level. Partial budget and marginal analysis were conducted based on CIMMYT (1988).

Statistical Analysis of Data

All maize and soybean yield and biomass data were subjected to analysis of variance (ANOVA) with the RCBD design using Statistical Analysis System (SAS

Institute, 2012) 9.3 Version software using proc GLM procedure. LSD was used to separate significantly differing treatment means after treatment effects were found significant at $P \leq 0.05$.

Results and Discussion

Effects of micro-dosing quick Lime (CaO) on Soil chemical properties

Calcium oxide lime had no significant effect on soil pH, available phosphorus, organic carbon and total nitrogen at study site (Figures 1). This is attributable to the slow solubility of lime and hence low mobility within the soil (Yorst & Ares, 2007). Very little changes in soil pH, exchangeable Ca2+ and Al3+ were reported in the sub-soil (12 -85 cm depth) after lime application at rates between 1.5 – 6.0 tons CaCO3 ha^{-1} (Arya, 1990). Statistically, there was no significant variation among different rate of calcium oxide or statistically these different rates of lime /CaO were at par.

Effects of micro-dosing quick Lime (CaO) on soybean grain yield, yield parameter, biomass and growth parameters

Soybean grain yield, pod/plant, biomass and plant height data is presented in Table below. The agronomic growth parameters yield and yield components of soybean indicated there was significant difference among the treatments on both cropping seasons. The highest mean annual grain yield 19.13 Qu/ha was obtained from plot treated with 33% of CaO. During the first year (2019/201) of the experimentation the tallest plant height 60.74 cm were recorded from 33% CaO treated plots (Table below). And during 2020 cropping season the maximum pod/plant 62.49 pod/plant was recorded from 33% CaO treated plots (Table below).Micro-dosing lime increased fertilizers recovery efficiencies primarily by restoring soil pH to levels that are favorable for plant growth and microbial activity. It also eliminated toxic elements and ensured the availability of essential elements. Under such optimal growth conditions crops are able to absorb and use fertilizers more efficiently (Adams & Martin, 1984). Therefore, it is evident from this study that higher fertilizer efficiencies in acid soils can be achieved through micro-dosing lime. From these results we observed that application of small amount of quick (CaO) lime is possible to amend acid soil than application of huge amount of lime on acidic affected soil. According to Twomlow *et al.*, (2010) micro-dosing results in higher nutrient use efficiency and ultimately improve productivity. Earlier studies have shown that micro dosing is one technology that can be affordable to farmers higher returns to farmers from the fertilizer quantities that they are able to purchase (Chianu and Tsujii, 2005; Twomlow *et al.*, 2010)

At Mettu, the result indicated that there was statically significant different among the treatments for maize experiments. The maximum mean maize grain 6268.9 kg/ha were recorded from 33% micro-dosing quick lime (CaO) treated plots. The increased maize grain yield due to micro-dosing quick lime application reported in this study confirm work by several authors that soil acidity limit maize production in these soils. In Kenyan highland acid soil 25-50% of the actual lime requirement increased maize grain yield by about 106 and 13-27%, respectively (Kisinyo, 2011) while Opala *et al.*, (2007) observed significant responses to application of only 6 kg P ha-1. Remediation of acidic soil with application of lime has been widely practiced and recommended by several researchers to reduce the negative effects of soil acidity on soil fertility and crop productions (Rowell, 1994; Anetor and Ezekiel, 2006 and Brady and Weil, 2008).

From this results we also observed that application of small amount of quick (CaO) lime is very important than application of huge amount of $CaCO_3$on acidic affected soil. Even if the maximum mean grain yield was obtained from maximum rate of quick lime economically the best and feasible treatment is 6.25 % of quick lime. Application of small amounts of lime significantly increased maize grain yield suggesting that micro-dosing has the potential to increase maize production on acid soil of P deficient Jimma and Mettu.

Many researchers have been conducted research in different parts of Ethiopia with large amounts of lime (Anteneh Abewa *et al.*, 2013; Asmare Melese and Markku, 2016 and Endalkachew Fekad *et al.*, 2017) who reported that large amounts of lime had tremendous role in the change of soil chemical properties of acidic soils.

However, some researchers such as, Jafer Dawid and Gebresilassie Hailu (2017) recommend spilt application of lime application because of without a significant yield loss and harming soil health, splitting lime into one third and half and applying in three and two consecutive years, give similar yield with the full rate of lime applied once in the first year.

Table.1 Treatments and there description

Treatments in percentage and in kg/ha (CaO)	
CaO%	CaO in kg/ha
T1: 0%	0.00
T2: 6.5%	112.3
T3: 12.5%	224.6
T4: 25%	449.2
T5: 33%	598.3

Table.2 Initial soil chemical properties before planting of the study area

Jimma(soybean)			Mettu (maize)	
pH	Exchangeable acidity		pH	Exchangeable acidity
4.51	2.12		4.43	1.6

Table.3 Effects of micro-dosing quick lime (CaO) on grain yield of soybean at Jimma

Trts		Set I Quick lime CaO		
		2019	2020	Mean
%	Kg/ha	GY Qu/ha	GY Qu/ha	
Cont.	0.00	14.86^{c}	10.52^{d}	12.69^{d}
6.25%	112.3	16.81^{bc}	13.17^{c}	14.99^{c}
12.5%	224.6	18.95^{ab}	14.76^{bc}	16.85^{bc}
25.0%	449.2	19.45^{ab}	16.33^{ab}	17.89^{ab}
33.3%	598.3	20.41^{a}	17.86^{a}	19.13^{a}
LSD		2.94	2.02	1.97
CV		8.62	7.38	6.45

Where, CV= Coefficient of variation, LSD= List Significant Different, GY=Grain yield

Table.4 Effects of micro-dosing of CaO on biomass yield of soybean at Jimma

Trts(%)	Quick lime CaO		
	2019	2020	Mean
	BM t/ha	BM t/ha	
Control	6.13d	5.48d	5.81d
6.25	7.36cd	6.24c	6.80c
12.5	8.43cb	6.70bc	7.56bc
25.0	9.3b	7.11b	8.20b
33.3	10.6a	8.51a	9.56a
LSD	1.24	0.73	0.82
CV	7.92	5.69	5.76

Where, CV= Coefficient of variation, LSD= List Significant Different, BM=Biomass

Table.5 Effects of micro-dosing of CaO on pod number and plant height of soybean at Jimma

Trts (%)	Quick lime CaO	
	Year 2 (2020)	
	pod/plant	Plant height(cm)
Control	37.00c	50.49cd
6.25	38.33c	53.29c
12.5	41.73b	54.06bc
25.0	43.60ab	57.68ab
33.3	44.13a	60.74a
LSD	2.115	4.16
CV	2.74	4.04

Where, CV= Coefficient of variation, LSD= List Significant Different

Table.6 Effects of micro-dosing of CaO on grain yield of maize at Mettu

CaO %				
Treat(%)	Kg/ha	2019	2020	Mean
		Yld kg/ha	Yldkg/ha	Yld kg/ha
0.00	0.00	4033.3d	3294.4c	3663.9d
6.25	112.3	5401.2c	4736.7b	5069c
12.5	224.6	5876.7bc	5286.1ab	5634.3bc
25.0	449.2	6193.9ab	5391.9ab	5740ab
33.3	598.3	6700.2a	5837.6a	6268.9a
LSD		648.83	708.47	572.19
CV		6.1	7.65	5.76

Where, CV= Coefficient of variation, LSD= List Significant Different, Yld=Yield

Table.7 Partial budget analysis for micro dose of CaO lime rates on soybean at Jimma

Treatments	TY	ATY	GFB	TVC	NB	MRR %
Cont.	1269	1142.1	39973.50	0	39973.50	0.00
6.25	1499	1349.1	47218.50	326.40	46892.10	**2119.67**
12.5	1685	1516.5	53077.50	652.80	52424.70	1695.04
25	1789	1610.1	56353.50	1315.20	55038.30	394.57
33.3	1913	1721.7	60259.50	1752.00	58507.50	794.23

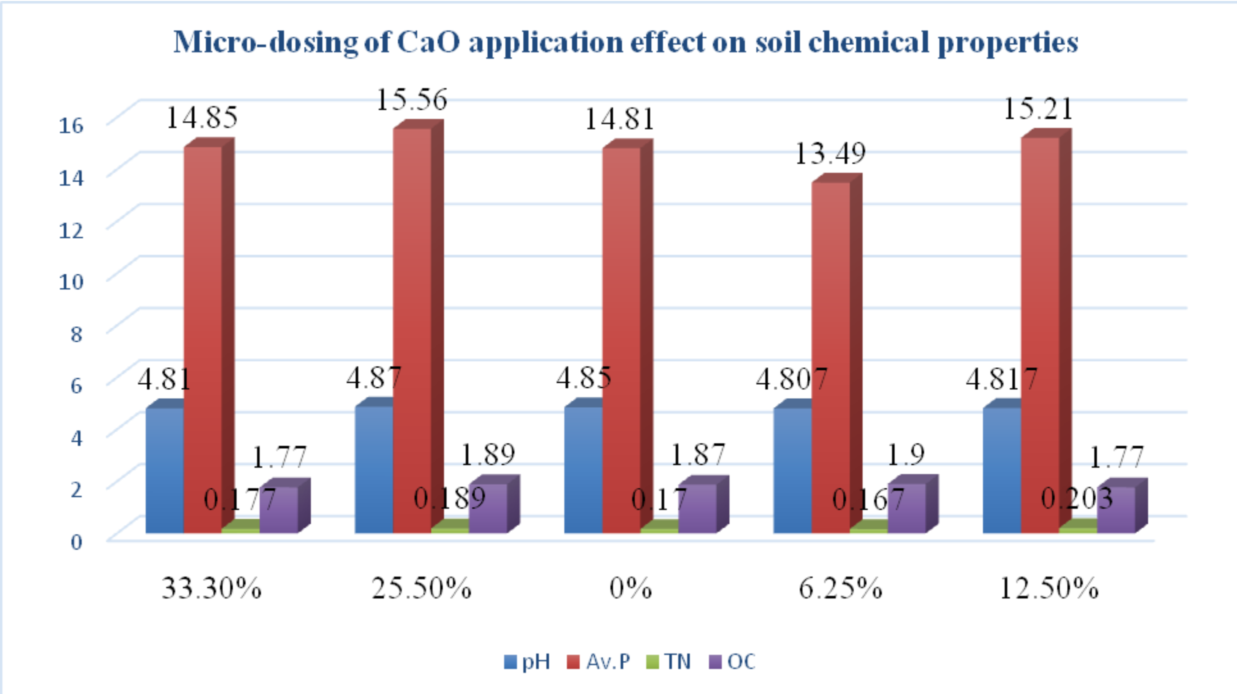
TY= Total yield, **ATY**=Adjusted Total yield, **GFB** =Gross Field Benefit, **TVC**=Total variable coast, **NB**=Net Benefit **MRR**=Marginal Return rate

Table.8 Partial budget analysis for micro dose of CaO lime rates on Maize at Mettu

Treatments	TY	ATY	GFB	TVC	NB	MRR%
Cont.	3663.9	3297.51	39570.12	0	39570.12	0.00
6.25	5069	4562.1	54745.20	326.40	54418.80	**4549.22**
12.5	5634.3	5070.87	60850.44	652.80	60197.64	1770.48
25	5740	5166	61992.00	1315.20	60676.80	72.34
33.3	6268.9	5642.01	67704.12	1752.00	65952.12	1207.72

TY= Total yield, **ATY**=Adjusted Total yield, **GFB** =Gross Field Benefit, **TVC**=Total variable coast, **NB**=Net Benefit **MRR**=Marginal Return rate

Fig.1



The increased growth and yield due to lime application are in agreement with (Kabambe *et al.*, 2013; Mtonga, 2013; Kisiyo, 2015; The, 2012) and is agreement with recommendation to apply lime for soils with pHw<5.5 (Chilimba and Nkosi, 2014). It of interest to note the significant yield increase to the lower lime rates as applied by point placement.

Rates of 6.25% ha^{-1} is substantially lower and would be relatively feasible for smallholder farmers compared to 33.3% ha^{-1} high rate among used treatments. The *et al.*, (2012) reported that application of lime at the rate of 250 kg ha^{-1} increased maize grain yield in some varieties of maize, but not others. However, agricultural lime applied at high rates to a large volume of soil has advantage of residual effects which may last for 2-3 seasons.

Partial budget analysis

Partial budget analysis was carried out following CIMMYT (1988) procedure based on local market price. The study revealed that except control treatments on maize and soybean, all the other treatments were similar. The highest net benefit of BIRR 65952.12 $ha^{-1}$was obtained from application of 33.3 percent of CaO and marginal rate of return 4549.22% was obtained from application of 6.25 percent of CaO for maize production. Similarly, the highest net benefit of BIRR 58507.50 ha-1 was obtained from application of 33.3 percent of CaO and marginal rate of return 2119.67% was obtained from application of 6.25 percent of CaO for soybean production. The lowest net benefit was (Table 8-9) recorded from the control plot. Therefore, micro dosing application is the most economically affordable treatments after all treatments. The result is in agreement with Chianu and Tsujii (2005) and Twomlow *et al.*, (2010) who reported that micro dosing is one technology that can be affordable to farmers and ensures that poor farmers get the highest returns from are able to purchase.

Recommendations

The results consistently demonstrate that 6.25% ha^{-1} of quick lime as micro dose resulted in better maize growth and yield compared to no lime and 12.5% ha^{-1} treatment rate. The results suggest potential to reduce application rates and increase yield of maize through micro-dosing of agricultural lime and provide a solid basis for wider evaluation of the concepts for subsequent rolling out to famers.

Profitability was clearly related to yield and the associated costs of production. These results are from an explorative study. As the concept of micro-dosing, as defined here, is the reduction of application rates and the precise point placement. From this results we observed that application of small amount of quick (CaO) lime is very important than application of huge amount of lime on acidic affected soil.

The economic analysis result indicated that applying lime in micro dosing was economically feasible. Therefore, micro dosing application of lime is an efficient and economically affordable method for small scale farmers. Finally, because of farmers makes their decisions on economic evaluation to adopt this technology, economic analysis were considered and 6.25% of lime application were economically feasible than other treatments. Small scale farmers could use micro dosing application of CaO lime to sustain the soil acidity problems of the soil without compromising yield of maize and soybean for a time being. However, it is recommended that it should be evaluated along with other integrated soil management options that are proven to ameliorate soil acidity and improve yields.

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