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Split Application of Calcium Carbonate for Acid Soil Amelioration, Soybean and Maize Performance in Acid Prone Areas of Southwestern Ethiopia

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Abstract

The high cost of inorganic fertilizers and high amount of lime application has precluded their use by smallholder farmers to remedy the problem of soil acidity and infertility in Ethiopia. To address the problem, we tested a precision technique referred to as micro-dosing of CaCO3 which involves application of small, affordable quantities of calcium carbonate on an acid soil in Jimma and Ilu Abba Bora, Ethiopia. Experimental treatments were CaCO3 (0, 6.5, 12.5, 25 and 33% of recommended lime based on calcium carbonate equivalence) of the actual requirement. Maize and soybean grain yield and above ground biomass were determined. CaCO3 were significantly affected both soybean and maize grain yield, above ground biomass and number of pods per plant for soybean. The highest grain yield of soybean was14.2Qu/ha and biomass were 7.69t/ha due to 33% of CaCO3 lime application. Similarly, the highest grain yields of maize were 57.39 Qu /ha due to 33% of CaCO3 lime application. However, economically 6.5 % CaCO3 is the best or economically feasible. Therefore, micro-dosing of CaCO3 can increase maize and soybean production on acid soils of Jimma and Ilu Abba Bora area and micro-dosing application of CaCO3 was an efficient and economically affordable method for small scale farmers.

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Keywords

Soil acidity, CaCO3, Liming, Micro-Dosing, Maize and Soybean.

Introduction

Soil acidity associated to Al toxicities, soil erosion and soil nutrient depletion are the main soil related constraints to agricultural development in parts of developing countries relying on agricultural to feed their growing population (Kisinyo, 2014). The summation of different anthropogenic and natural processes including leaching of exchangeable bases, basic cation uptake by plants, decomposition of organic materials, application of commercial fertilizers and other farming practices produce acidic soils (Brady and Weil, 2008). The major soil forming factors that includes; climate, vegetation and parent material, are among the major factors that increase soil acidity in the country (Mesfin, 2007). In Ethiopia, huge surface areas of the highlands located at almost all regional states of the country are affected by soil acidity. From current (Ethiosis, 2014) report it was estimated that about 43% of the total arable land in Ethiopia is affected by soil acidity. Soil acidity problem is significant in the north-western, south-western, southern and central regions of the country which receive precipitation high enough to leach down soluble salts and/or basic cations appreciably from the surface layers (root zone) of the soils. Some of the well-known areas severely affected by soil acidity in Ethiopia are Ghimbi, Nedjo, Hossana, Sodo, Chencha, Hagere-Mariam and Awi Zone of the Amahara Regional State (Ethiosis, 2014).

To promote food production among resource constrained acid prone areas, in the recent past; a lot of interest has been geared towards finding an efficient and sustainable fertilizer use (Nziguheba, 2007). Micro-dosing, which comprises of use of small and affordable amounts of lime (CaCO3)at planting or top dressing. In Zimbabwe for example micro-dosing of 25 – 33% of the recommended N fertilizer increased maize grain yield in resource poor farmers fields (ICRISAT, 2009). This enhanced the adoption of fertilizer inputs among the resource poor farmers. Research has suggested that with an application of as little as 10 kg N ha^{-1}, farmers can increase their crop yield by 50-100% (ICRISAT, 2009). On acid soils, lower rates of fertilizers can be applied together with lime to achieve higher fertilizer nutrient use efficiencies since lime reduces soil acidity related constraints (Kisinyo, 2014). Most research on micro-dosing has been in different parts of the world using mainly inorganic fertilizers in combination with lime on acid sol. The main problem with most of the current acid soil management recommendations is that they target maximization of yields or profits without consideration of the agricultural risks and resource constraints faced by many smallholder households (Twomlow *et al.,*).Therefore, there is need to test the technology on high acid soils prone areas where soil acidity limit crop production thereby threatens the livelihood of small-scale farmers. The study will benefit resource poor farmers who can't afford and apply full dose of recommended lime.

Materials and Methods

The study area, Experimental design, Treatment and procedure

Field experiments were conducted with CaCO3 using soybean and maize as a test crop in two sets separately 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 site. CaCO3 were applied yearly for each treatment accordingly. 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 CaCO3 (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 to each treatment 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

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

Where

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

EA = Exchangeable acidity

The lime rates set based on 100% recommendation were applied in micro dosing application uniformly by hand in row and mixed in the top 15 cm soil layer at planting according. Recommended rate of N (46kg ha^{-1}) and (92kg 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 nitrogen 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.

Soil sampling and analysis

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.

Data analysis

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, 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 Discussions

Effects of CaCO3on selected Soil chemical properties

Figure 1 shows the effect of lime on soil pH, Available P, organic carbon (OC) and Total Nitrogen (TN). Statistically there was no significant variation among all lime rates. Even if there was no significant variation among lime treatment for selected soil chemical properties, there was the yield increments with increasing lime rate. For Total Nitrogen both lime rate increased soil TN higher than the control. In tropical acid soils, lime have been reported to increase TN above the control for a longer period (Kisinyo, 2014). Lime rate at 12.5 reach the highest peak of available P values of 12.4.

Effects of micro-dosing of CaCO3 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 14.21 Qu/ha was obtained from plot treated with 33% of CaCO3 (Table 4). During the first year (2019/201) of the experimentation the maximum pod/plant 44.13 were recorded from 33% CaCO3 treated plots (Table 5). Similarly, during 2020 cropping season the maximum plant height 39.06 was recorded from 33% treated plots (Table 6). From these results we observed that application of small amount of CaCO3 is very important than application of huge amount of $CaCO_3$on acidic affected soil in economic point of view. According to (Twomlow *et al.*,) 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). At Mettu, the result indicated that there was statically significant different among the treatments for maize experiments. The maximum mean maize grain 5739.9 kg/ha were recorded under 33% of $CaCO_3$treated plots. 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).

From these results we also observed that application of small amount of lime is very important than application of huge amount of $CaCO_3$on acidic affected soil by economic point of view. Even if the maximum mean grain yield was obtained from maximum rate of lime economically the best and feasible treatment is 6.25 % of lime. Many researchers have been conducted research in different parts of Ethiopia with large amounts of lime (Anteneh Abewa *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.

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 59366.3ha^{-1} was obtained from application of 33.3 percent of CaCO3 and marginal rate of return 1534.60% was obtained from application of 33.3 percent of CaCO3 for maize production. Similarly, the highest net benefit of BIRR 43678.86ha-1 was obtained from application of 33.3 percent of CaCO3 and marginal rate of return 1289.12% was obtained from application of 33.3 percent of CaCO3 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 (4 and15) 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.

Table.1 Treatments and their description

$CaCO_3$%	$CaCO_3$ in kg/ha
T1: 0%	0
T2: 6.5%	168
T3: 12.5%	337
T4: 25%	674
T5: 33%	897.5

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 CaCO3 micro-dosing on grain yield of soybean at Jimma

TRT (CaCO3)		2019	2020	Mean
(%)	Kg/ha	GY Qu/ha	GY Qu/ha	
Cont.	0.00	14.26^{c}	9.72^{b}	11.98^{b}
6.25%	168	14.53^{c}	10.95^{ab}	12.74^{b}
12.5%	337	15.13^{b}	10.93^{ab}	13.03^{ab}
25.0%	674	15.80^{ba}	10.66^{ab}	13.02^{ab}
33.3%	897.5	15.80^{a}	12.60^{a}	14.21^{a}
LSD		0.60	2.03	1.21
CV		7.2	9.85	4.96

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

Table.4 Effects of CaCO3 micro-dosing on biomass yield of soybean at Jimma

Trt (%) CaCO3	2019	2020	Mean
	BM t/ha	BM t/ha	
Control	4.7c	5.40a	5.20c
6.25	5.3c	5.70a	5.46c
12.5	6.9b	5.72a	6.32b
25.0	7.9b	5.97a	6.93b
33.3	9.3a	6.06a	7.69a
LSD	1.17	NS	0.65
CV	9.05	6.20	5.52

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

Table.5 Effects of CaCO3 micro-dosing on pod number and plant heightof soybean at Jimma

Trts (%)$CaCO_3$	Year 2 (2020)	
	pod/plant	Plant height(cm)
Control	27.40b	52.22d
6.25	30.00b	55.56cd
12.5	32.60ab	56.90bc
25.0	34.13ab	59.16ab
33.3	39.067a	62.49a
LSD	7.014	3.45
CV	11.41	3.2

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

Table.6 Effects of CaCO3 and CaO on grain yield of maize at Mettu

Treat (%)	Kg/ha	CaCO3		
		2019	2020	Mean
		Yld kg/ha	Yld kg/ha	Yld kg/ha
0.00	0.00	3815.1d	2980.4c	3397.7d
6.25	168	4840.2c	3359.1c	4099.6c
12.5	337	5108.6bc	4059.2b	4583.9b
25	674	5377.8b	4121.8b	4749.8b
33.3	897.5	6392.7a	5087a	5739.9a
LSD		532.71	693.76	356.65
CV		5.54	9.39	4.19

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

Table.7 Partial budget analysis for micro dose on CaCO3 lime rates on soybean at Jimma

Treatments	TY	ATY	GFB	TVC	NB	MRR %
Cont.	1198	1078.2	37737.00	0	37737.00	0.00
6.25	1274	1146.6	40131.00	203.20	39927.80	1078.15
12.5	1303	1172.7	41044.50	406.40	40638.11	349.56
25	1302	1171.8	41013.00	812.79	40200.21	D
33.3	1421	1278.9	44761.50	1082.64	43678.86	**1289.12**

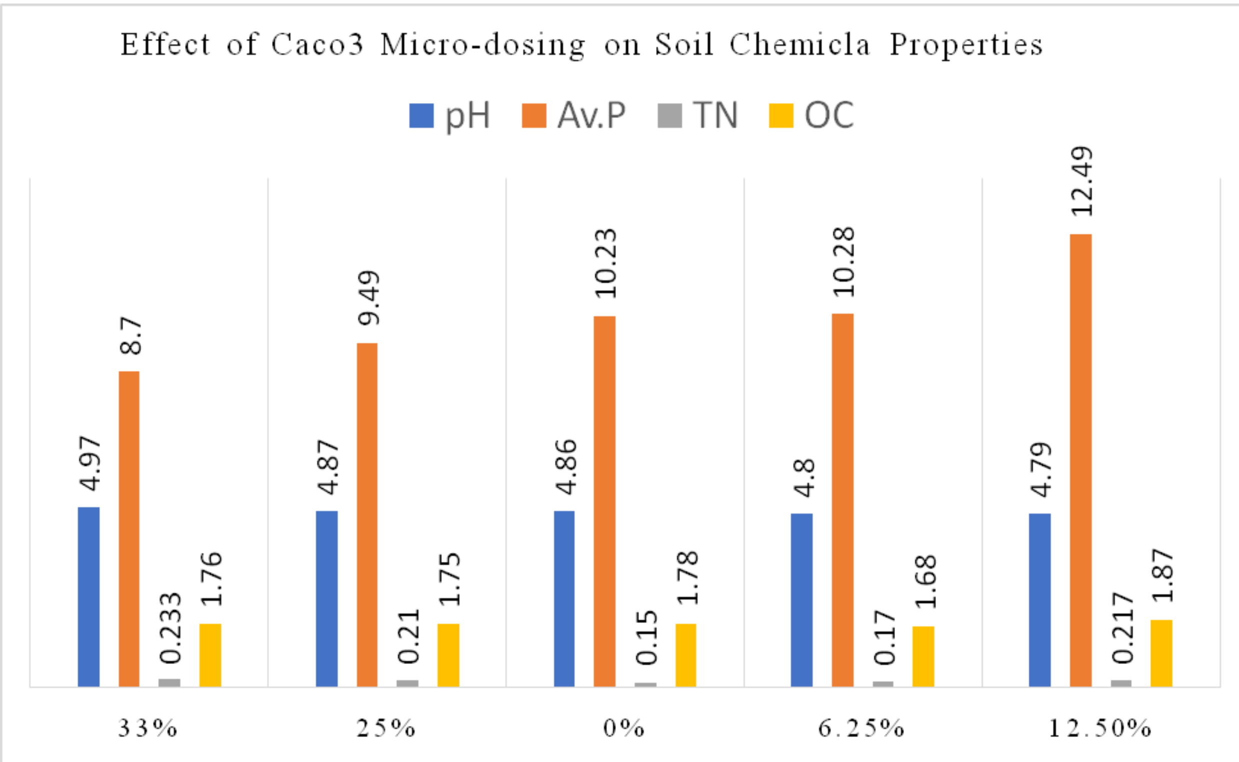
TY= Total yield, **ATY**=Adjusted Total yield, **GFB** =Gross Field Benefit, **TVC**=Total variable coast, **NB**=Net Benefit
MRR=Marginal Return rate

Table.8 Partial budget analysis for micro dose on $CaCO_3$ lime rates on Maize at Mettu

Treatments	TY	ATY	GFB	TVC	NB	MRR%
Cont.	3397.7	3057.93	36695.16	0	36695.2	0.00
6.25	4099.6	3689.64	44275.68	492.60	43783.1	1438.00
12.5	4583.9	4125.51	49506.12	985.20	48520.9	961.80
25	4749.8	4274.82	51297.84	1970.40	49327.4	81.86
33.3	5739.9	5165.91	61990.92	2624.57	59366.3	**1534.60**

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

Fig.1 Effect of $CaCO_3$ lime micro-dosing rate on chemical properties of soil



Recommendations

The study was conducted to investigate the effect of micro-dosing of lime on selected soil chemical properties and yield and yield components of maize and soybean. Micro-dosing of lime /Application of small amounts of lime significantly increased maize grain yield suggesting that micro-dosing has the potential to increase maize and soybean production on Jimma and Mettu nutrient deficient acid soils. From these results we observed that application of micro-dosing is very important than application of huge amount of limeon 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 was considered and 33.3 % of lime application were economically feasible.

From the conclusions of the study, the following recommendations can be drawn. Since soils of the study area are affected by soil acidity, lime application is recommended for achieving higher yield of maize and soybean. Micro-dosing of liming is more effective than full dose due to low cost, easy of transportation, possibility of mixing it to the soil during planting and to save wastage of lime. Small scale farmers could use micro dosing application of lime to sustain the soilacidity problems of the soil without compromising yield of maize and soybean. Further study should also be done for further evaluation and to the residual effects.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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