Evaluation of different doses of lime applied in rows at planting on bread wheat yield in West Amhara, Ethiopia

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Abstract

The need for the application of high amount of lime per hectare due to high soil acidity hindered wider dissemination of liming by the smallholder farmers in Ethiopia in general and in Amhara region inparticular due to high transportation cost. Therefore, a field experiment was conducted to evaluate the effect of row application of different doses of lime at planting on bread wheat yield in the acidic soils of Gozamin and Banja districts, west Amhara. The experiment was comprised of nine treatments including (5, 10, 12.5, 20, 25, 100, 150% of the full dose of lime calculated based 1.5x exchangeable acidity, 2 tons of lime and control (without lime). The treartments were arranged in a randomized complete block design with three replications. The 5-25% of the full dose of lime were applied in rows by drilling at planting. While 100, 150% and 2 tons of lime per hectare were applied by broadcasting at planting. The recommended DAP and half of urea were applied at planting to all treaments uniformily. While half of the recommended urea was applied at tillering. All soil and agronomic data were collected following the standard procedures. All collected data were subjected to GLM using SAS software and significant mean differences were computed by least significant difference at 5% level of significance. The statistical analysis showed that application of 25% and 20% of the full dose of lime with recommended fertilizer gave 1087.9 and 972.2 kg ha^{-1} grain yield difference compared to the recommended fertilizer alone respectively at Gozamen. Similarly, the yield difference between the application of 25% and 20% of the full dose of lime with recommended fertilizer compared to the recommended fertilizer alone was 1317.6 and 827.4 kg ha^{-1} respectively at Banja. The soil pH was increased from 4.48 to 5.32 due to the application of 25% of the full dose of lime and from 4.48 to 5.22 due to the application of 20% of the full dose of lime. The exchangeable acidity was also decreased from 1.59 to 0.04 due to the application of 25% of the full dose of lime and from 1.59 to 0.65 due to the application of 20% of the full dose of lime at both locations. Application of 25% of the full dose of lime will benefit the smallholder farmers by reducing the cost of lime and its transportation. Hence, 25% of the full dose of lime with the recommended fertilizers is recommended for Banja, Gozamen and similar agroecologies to reclaim acidic soils.

Key words: Acidic soil, Banja, Gozamen, liming, micro dozing

Introduction

The success in soil management to maintain soil quality depends on an understanding of how soils respond to agricultural practices over time. However, land degradation is one of the challenges facing Ethiopian agriculture. Among the land degradations soil erosion and soil fertility depletion are current problems hindering crop production in Ethiopia. One of the soil chemical degradation challenging the Ethiopian highland soils is soil acidity which can be caused by leaching and plant uptake of basic cations (Ca and Mg), production of organic acids from organic matter decomposition, and application of acidifying N fertilizers (Ammonium/ammonia N sources including products like urea) (Bierman and Carl, 2005). Acid soils are rampant and occupy about 40.9 percent of the country (Mesfine A., 2007; Schlede, H., 1989). They extend from south-west to north-west with east-west distribution (Mesfine A., 2007). They are concentrated mainly in the western part of the country including the lowlands but are limited by the eastern escarpments of the Rift Valley (Mesfine A., 2007). Out of the 40.9 percent total coverage, 27.7 percent are moderate to weakly acidic (pH of 5.5 - 6.7); 13.2 percent are strong to moderately acidic (pH< 5.5) and nearly one-third have aluminum toxicity problem (Schlede, H., 1989). From the soil analysis result by Bahir Dar, Debremarkos and Gonder soil laboratories indicate that north west Ethiopia especially the highlands of Gojam and Gonder are dominated by soil acidity problems (unpublished data).Soil acidity affects productivity of the soil through its effect on nutrient availability and toxicity by some elements like aluminum and manganese; most plant nutrients become more limited in supply, and a few micronutrients become more soluble and toxic. These problems are particularly acute in humid tropical regions that have been highly weathered (Harter, 2002).As soils become more acid, particularly when pH drops below 4.5, it becomes increasingly difficult to produce food crops. Aluminum and manganese become more soluble (i.e. more of the solid form of these elements will dissolve in water when the soil is acid) and toxic to plants, most plant nutrients become more limited in supply, and a few micronutrients become more soluble and toxic. The ideal soil pH for most crops is slightly acidic to neutral (pH in water 6-7). Favorable soil pH in water for wheat production is 5.5 -7 below this pH ranges especially below 5.1- 5.5 wheat production is severely affected due to toxicity of aluminum and unavailability of macronutrients (Fenton and Helyar, 2007). The critical aluminum level extracted by CaCl2 solution for wheat production is 0.4-0.8 ppm in which aluminum toxicity will affect wheat production (Fenton and Helyar, 2007). High levels of soil acidity (low soil pH) can cause reduction of root growth, nutrient availability, affect crop protecting activity (Douglas, 2001), reduction and total failure of crop yields and deterioration of soil physical properties. In general it affects the biological, chemical and physical properties of soil, which in turn affect the sustainability of crop production in both managed and natural ecosystem.

Reclamation and maintenance of soil acidity is very important soil management practices for crop production. Lime is the major means of ameliorating soil acidity (Anetor and Ezekiel, 2007); because it has very strong acid neutralizing capacity and can effectively remove existing acid. Liming increases the uptake of nutrients, stimulate biological activity and reduce toxicity of heavy metals. Liming raises the soil pH and causes the aluminum and manganese to go from the soil solution back into solid (non-toxic) chemical forms. Regular applications of lime are required on many soils to maintain soil pH in the desired range, because soil acidification is an ongoing process (Bierman and Carl, 2005). Limestone is the most commonly used material to increase soil pH. However, for most efficient crop production on acid soils, application of both lime and fertilizer are required. Since lime make minerals more available to plants, liming without fertilizers application results in soil fertility decline that might lead to serious problem of production. Therefore, applying fertilizer to correct nutrient constraints caused by acidity is necessary. Lime and fertilizer management practices are primary important for proper management of acid soils. Research attempts are made at different parts of the country (Agumas et al, 2016a; 2016b; Agegnehu et al 2017; Abay A. 2011; Chimeda et al. 2012), to look for viable solutions for acidic soil for small holder farmers. According to Agumas et al. (2016a), the amount of lime applied to reclaim acidic soil was 1.5x exchangeable acidity of that specific soil. According to Mosisa (2018), 5-16.5 t ha^{-1} lime rates are recommended depending on the extent of soil acidity. However, smallholder farmers are complaining the current lime rate because of very high cost and beyond their purchasing capacity. Due to this challenge, lime application did not expand as expected and only 6% of the agricultural lands are receiving lime and only 7% of targeted farmers are applying lime nationwide (Gurmessa, 2020). Therefore, this experiment was designed to evaluate cost effective and affordable lime application techniques to improve crop production and reclaim acidic soil in Amhara region in particular and in Ethiopia in general.

Material and methods

Description of the Study Area

The experiment was conducted on IDUPHUV¶ field at Enerata Kebele of Gozamen district and Akayita Kebele of Banja district from 2012-2013 cropping season on permanent plots for two consecutive years. Gozamen district is located in East Gojam administrative Zone of Amhara National Regional State. Enerata Kebele is traversed by a gravel road that passes from Debremarkos town to Sinan district i.e about 7 km from Debremarkos town. Geographically, the kebele is located at 37^{0} ¶ ¶¶ (DVW ORQJLWXGH DQG 10^{0} 4¶ 1RUWK /DWLWXGH. Akayita kebele is located on Banja district of Awi administrative zone. The Kebele is around three kilometer from Injibara town to the way to Addis Abeba city. The areas are situated within the Abay basine.

Experimental procedure and treatment set up

)URP IDUPHUV¶ ILHOG FRPSRVLWH soil samples were collected from 0 ±15 cm depth and analyzed for exchangeable acidity and pH prior to planting. For the second and third times soil samples were collected during harvesting. 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 sample density and exchangeable Al^{+3} and H^{+1} of each site. Assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$. The amount of lime required per hectare (full dose) was calculated based on the following formula.

$$LR, CaCO_3\ (kg/ha) \quad \frac{cmolEA/kg\ of\ soil * 0.15\, m * 10^4\ m^2 * B.D.\,(Mg/m^3) * 1000}{2000} * 1.5 \qquad \text{-Eq-1}$$

The full dose of lime was applied at once in the first year by broadcasting during planting. The recommended N and P were applied uniformly to all treatments. For the broadcast application, lime was broadcasted uniformly by hand and incorporated into the soil during planting while for the row application lime was applied at planting in rows in each year. Urea and DAP was used as the source of N and P, respectively. Application of urea was applied in two splits, while the entire rate of phosphorus was applied at planting. Improved wheat variety (TAY) was used as a test crop. During the second year those plots which received full dose of lime did not get lime while those plots which received lime on row application also received lime again for the second year according to the treatment set up. For the second year land preparation was done using man power to restrict mixup of different plots. The experiment was laidout in RCBD with three replications. Weeding and frequent follow up was conducted as per visual observations and there was no crop rotation that was wheat after wheat for the second year. Gross and net plot size were 1.6mX3m = 4.8m^2 and 1.2mX3m= 3.6m^2 respectively.

treatments:

1. 25% of full dose of lime calculated based on equation-1 applied in row
2. 20% of full dose of lime calculated based on equation-1 applied in row
3. 12.5% of full dose of lime calculated based on equation-1 applied in row
4. 10% of full dose of lime calculated based on equation-1 applied in row
5. 5% of full dose of lime calculated based on equation-1 applied in row
6. 100% of full dose of lime calculated based on equation-1applied in broadcasting
7. 150% of full dose of lime calculated based on equation-1applied in broadcasting
8. 2 tons of lime per hectare (recommended by regional soil laboratory)
9. Control no lime with recommended urea and DAP.

Table 1. Initial soil physico-chemical properties and lime calculated for each site

Woreda	pH	BD	Ex. Al	Ex. H	Ex. acidity	OM	Texture	Lime kg ha^{-1}	Lime Kg ha^{-1} (1.5x)
Gozamen	5.28	1.67	0.90	1.09	2.0	3.36	Heavy clay	2508.7	3763
Banja	4.47	1.15	2.29	1.28	3.22	5.21	Silt clay	2783.6	4175.3

BD; bulk density, Ex.Al; exchangeable aluminium, Ex.H; exchangeable hydrogen, Ex.acidity; exchangeable acidity

Results and discussion

Response of bread wheat yield to different lime amount and application methods

The statistical analysis at Gozamen indicated that there was significant variation among treatments in grain yield at $p<0.05$. The maximum grain yield (3125 kg ha^{-1}) was obtained from 2 t lime ha^{-1} combined over years (Table 2) and it was at par with the yield obtained from 25% (2847 kg ha^{-1}), 150% (2800 kg ha^{-1}), 20% (2731 kg ha^{-1}), and 100% (2581 kg ha^{-1}) of the full dose of lime. However, there was no significant difference among different doses of lime except with 5%, 10% of the full dose of lime and the control (Table 2). There was 61.9% yield advantage of applying 25% of full dose of lime with the recommended fertilizer rate over the recommended fertilizer rate alone at Gozamin.

Similarly, combined over years, the statistical analysis at Banja showed significant difference in grain yield among the treatments (Table 3). The maximum grain yield (3455 kg ha^{-1}) was obtained from the application of 25% of the full dose of lime.

Table 2. Influence of lime amount and application methods on yield of bread wheat at Gozamen (kg ha^{-1})

Lime amount and application method	2012	2013	Combined
25% of the full dose of lime calculated based on equation-1 applied in row	3611.1ab	2083.3a	2847.2ab
20% of the full dose of lime calculated based on equation-1 applied in row	3472.2ab	1990.7a	2731.5abc
12.5% of the full dose of lime calculated based on equation-1 applied in row	3148.2ab	1805.6ab	2476.9bc
10% of the full dose of lime calculated based on equation-1 applied in row	3009.3b	1435.2b	2222.2bcd
5% of the full dose of lime calculated based on equation-1 applied in row	2847.2b	1435.2b	2141.2dc
100% of the full dose of lime calculated based on equation-1 applied by broadcasting	3402.8ab	1759.3ab	2581.0abc
150% of the full dose of lime calculated based on equation-1 applied by broadcasting	3842.6ab	1759.3ab	2800.9ab
2 ton of lime per hectare recommended by regional soil laboratory	4305.6a	1944.4a	3125.0a
Control (no lime. With recommended urea and DAP alone)	2685.2b	833.3c	1759.3d
CV (%)	21.81	13.30	21.32
LSD (0.05)	1271.9	385	630.59

Table 3. Influence of lime amount and application methods on yield of bread wheat at Banja woreda (kgha^{-1})

Lime amount and application method	2012	2013	combined
25% of the full dose of lime calculated based on equation-1 applied in row	4418.5a	2490.7a	3454.6a
20% of the full dose of lime calculated based on equation-1 applied in row	4112.0ab	1816.7ab	2964.4ab
12.5% of the full dose of lime calculated based on equation-1 applied in row	3718.5ab	1737.5ab	2728.0abc
10% of the full dose of lime calculated based on equation-1 applied in row	3452.8ab	1342.6b	2397.7bc
5% of the full dose of lime calculated based on equation-1 applied in row	3249.0ab	1241.7b	2245.4bc
100% of lime calculated based on equation-1applied by broadcasting	4525.9a	1973.1a	3249.5a
150% of lime calculated based on equation-1 applied by broadcasting	4574.1a	1964.8a	3269.4a
2 ton of lime per hectare recommended by regional soil laboratory	4376.8ab	2292.6a	3334.7a
Control (nolime. With recommended urea and DAP alone)	3060.2b	1213.9b	2137.0c
CV (%)	19.45	25.52	21.85
LSD (0.05)	1327.3	789	734.53

Influence of lime dose and application methods on soil pH and exchangeable acidity at Banja and Gozamen districts, Ethiopia

The soil analysis result showed that the two locations are different in exchangeable acidity, organic matter content and texture (Table 1) which were resulted different doses of lime. According to Hazelton and Murph (2007), suitable pH for wheat production is 5.5 to 7; below which wheat production is severely affected by aluminum toxicity and unavailability of macronutrients (Fenton and Helyar, 2007). From the soil data, the pH of the testing sites were below 5.5 which means wheat production has been greatly affected by soil acidity. Similarly, the critical aluminum level extracted by $CaCl_2$ solution for wheat is 0.4 to 0.8 ppm, above this range aluminum toxicity will affect wheat production (Fenton and Helyar, 2007). The soil analysis result showed that aluminum content of the soil was greater than the critical level at Gozamen (2.0 ppm) and Banja (3.22 ppm) (Table 1).

In the first year, an increased pH was recorded by applying different lime amount in row application at Gozamen (Table 4). The maximum pH increment and minimum exchangeable acidity were recorded from 1.5x exchangeable acidity in broadcast application in the same location. Exchangeable acidity was decreased from 1.41 to 0.78 and similarly exchangeable aluminum was reduced from 0.94 to 0.47 in the first year by applying 25% of the amount of lime in row at the same research site. In the second year, the pH increased from 4.48 to 5.32 while the amount of exchangeable acidity decreased from 1.59 to 0.04 by applying 25% of the amount of lime calculated based on the above equation in row at Gozamen. Maximum increment of pH and minimum exchangeable acidity were recorded by applying maximum dose of lime. However, there was no significant difference in wheat grain yield between full dose, 1.5x full dose, 2 tone kg ha^{-1} limes, 25% and 20% of the full dose of lime.

Table 4. Effect of lime amount and application methods on pH and Exchangeable acidity of soil at Gozamen districts

Lime amount and application method	After a year of lime application (2013)				After two years of lime application (2014)			
	pH	Ex. acidity	Ex. Al	EX. H	pH	Ex. Acidity	Ex. Al	EX. H
25% of full dose of lime calculated based on equation-1 applied in row	4.87	0.78	0.47	0.31	5.32	0.04	0	0.04
20% of full dose of lime calculated based on equation-1 applied in row	4.97	1.2	0.67	0.53	5.22	0.96	0.13	0.84
12.5% of full dose of lime calculated based on equation-1 applied in row	4.97	1.25	0.79	0.46	5.33	0.03	0	0.03
10 of full dose of lime calculated based on equation-1 applied in row	5.05	1.37	0.83	0.54	5.36	0.28	0.14	0.14
5% of full dose of lime calculated based on equation-1 applied in row	5.03	1.27	0.75	0.52	5.36	0.84	0.26	0.58
100% of full dose of lime calculated based on equation-1applied by broadcasting	5.08	0.38	0.32	0.06	5.35	0.04	0	0.04
150% of full dose of lime calculated based on equation-1 applied by broadcasting	5.31	0.23	0.09	0.14	5.47	0.09	0	0.09
2 ton per hectare recommended by regional soil laboratory	5.13	0.98	0.49	0.49	5.37	0.31	0	0.31
Control no (lime with recommended urea and DAP)	4.35	1.41	0.94	0.47	4.48	1.59	1.07	0.52

Table 5. Effect of lime amount and application methods on pH and Exchangeable acidity of soil at BanjaWoredas

Lime amount and application method	After a year of lime application (2013)				After two years of lime application (2014)			
	pH	Ex. Acidity	Ex. Al	EX. H	pH	Ex. Acidity	Ex. Al	EX. H
25% of full dose of lime calculated based on equation 1 applied in row	4.90	2.32	1.24	0.84	5.77	1.00	0.89	0.11
20% of full dose of lime calculated based on equation 1 applied in row	4.85	2.48	2.08	0.40	5.82	2.18	1.64	0.54
12.5% of full dose of lime calculated based on equation 1 applied in row	4.73	2.84	2.09	0.76	5.68	2.34	2.00	0.35
10% of full dose of lime calculated based on equation 1 applied in row	4.71	3.16	2.31	0.85	5.85	2.42	1.90	0.52
5% of full dose of lime calculated based on equation 1 applied in row	4.74	2.84	2.20	0.74	5.53	2.34	1.77	0.57
100% of full dose of lime calculated based on equation-1applied by broadcasting	4.86	1.78	1.33	0.70	5.72	1.26	0.86	0.40
150% of full dose of lime calculated based on equation-1 applied by broadcasting	5.01	1.37	0.52	0.38	5.76	2.21	1.63	0.58
2 ton per hectare recommended by regional soil laboratory	4.89	1.73	1.10	0.64	5.83	2.01	1.34	0.68
Control no (lime with recommended urea and DAP)	4.68	3.22	2.29	1.28	5.53	2.53	1.92	0.61

At Banja, even though soil pH was below 5.5 after lime application in the first year it increased from 4.68 to 4.90 and 4.85 and exchangeable acidity was reduced from 3.22 to 2.32 and 2.48 when 25% and 20% of full dose of lime applied in rows respectively. Exchangeable aluminum concentration was reduced from 2.29 to 1.24 and 2.08 in the first year and from 1.92-to 0.89 and 1.64 in the second year by applying 25% and 20% of the full dose of lime. However, higher soil pH was recorded and increased from 5.53 to 5.77 to 5.82 at Banja in the second year. This might be due to sampling season variation in which the first year was during planting and in the second year at harvest which results great variation in the pH at both sites. Soil samples collected during rainy season has lower pH compared to those samples collected during dry season. Because during rainy season, there is leaching of cations and leads to reduced pH. From the result of both sites it was noticed that, there was no significant yield variation between full dose of lime and 20-25% of the full dose of lime while exchangeable acidity and aluminum were significantly reduced. Hence, instead of applying full dose of lime at once, application of 1/4 of the full dose of lime calculated based on 1.5x exchangeable acidity might be enough to increase wheat yield by reducing root zone acidity. This might be due to the neutralizing effect of lime in the root zone even though further investigation might be necessary in the future. In general, application of lime using micro dozing technique increased soil pH and reduces exchangeable aluminum and hydrogen which leads to increased wheat grain yield (Table 2-5). The amount of lime required in Banja was higher compared to Gozamen due to variation in soil buffering capacity of the two sites (Table 1). Generally, the buffering capacity of soil which is governed by texture, cation exchange capacity and organic matter determines the amount of lime required. The textural class of soils at Banja was silt clay and had very high aluminum concentration and the organic matter content was higher than at Gozamen which might also attributed to more lime requirement. This result was confirmed by Demil et al., 2020 who reported that applying only 25% of the full recommended rate of lime provided an advantage of mean grain yield of 4525 kg ha^{-1} and marginal rate of return of 252% compared to without lime.

Conclusion and recommendation

From the agronomic and soil data analysis results, it is possible to conclude that the contribution of lime application in micro dozing (in row) for acid soil rehabilitation was beneficial and an innovative approach. The result also confirmed that lime has great influence on grain yield as well as improving soil properties. Row application of 25% of the full dose of lime at planting also reduces the complaints of farmers by saving 3/4th of cost to be incurred by the smallholder famrers per hectare per year. However, lime application is not well practiced yet by the smallholder farmers in the region as well as in the country to curbe the effect of expanding soil acidification due to its bulkiness and difficulty for transportation. Hence, for bread wheat production application 25% of the full dose of lime calculated based on 1.5x exchangeable acidity in rows at planting is recommended for Gozamen and Banja districts and similar agroecologies. This finding should be further refined for different soil types, crops types and agro-ecologies in the future integrated with other soil acidity amelioration technologies.

Acknowledgement

The authors are grateful to Amhara Agricultural Research Institute and Adet Agricultural Research for the financial and other logistical supports to conduct the research. We also acknowledge researchers in soil fertility case team of Adet Agricultural Research Center for their assistance during the execution of this research and laboratory analysis.

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