Effect of lime and Phosphorus on soil health and bread wheat productivity on acidic soils of South Gonder.

[1]Birhanu Agumas, [2]Anteneh Abewa, [2]Dereje Abebe, [1]Tesfaye Feyisa, [1]Birru Yitaferu, and [3]Gizaw Desta

[1]Amhara Regional Agricultural Research Institute (ARARI), P.O.Box 527, Bahir Dar, Ethiopia

[2]Adet Agricultural Research Center (AARC), P.O.Box 08, Bahir Dar, Ethiopia

[3]Water and Land Resource Center (WLRC), Addis Ababa, Ethiopia

Abstract

A Field experiment was conducted at Farta, South Gondar in 2012 and 2013 to determine the lime correction factor using exchangeable acidity. A total of seven treatments including: lime determined using 1X and 1.5X of exchangeable acidity with half and full recommended P (23 and 46 kg P_2O_5 ha^{-1}), full recommended P alone (46 kg P_2O_5 ha^{-1}), full recommended P (46 kg P_2O_5 ha^{-1}) + blanket recommended lime (2 t ha^{-1}) and control (without lime and fertilizer) were arranged in a randomized complete block design with three replications. Recommended N was applied to all plots except the control (without input). Data were analyzed using SAS statistical software (SAS 2002) and the soil analysis was done following standard laboratory procedures. Economic analysis was also done using net present values with incremental net benefit. The result showed that lime (1.5X) + 46 kg P_2O_5 ha^{-1} + recommended N gave 20 % and 35% grain yield increment over the recommended NP at Minet and Tsegure respectively. Liming was also proved to improve the soil pH from 5.24 to 5.77 at Minet and from 5.24 to 5.75 at Tsegure. The exchangeable acidity and Aluminum was also significantly reduced at both sites. The maximum NPV (1019.2 Birr at Minet and 206.05 Birr at Tsegure) and incremental net benefits (36692.5 Birr at Minet and 7417.7 Birr at Tsegure) were obtained from lime (1.5X) + 46 kg P_2O_5 ha^{-1}. Therefore, lime (1.5X) + (recommended P and N) are recommended for Minet and Tsegure to improve soil chemical properties and increase wheat yield.

Keywords: Lime; acid soil, phosphorus, exchangeable acidity, bread wheat

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 to boost production in Ethiopia. One of soil chemical degradation challenging the highland soils of the country 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). The coverage of acid soils in Ethiopian highlands is widespread and occupies about 40.9 percent of the country (Schlede, 1989). The extent is extending from south-west to north-west with east-west distribution (Abebe, 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 (Abebe, 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, 1989). Western Amhara especially the highlands of Gojam, Awi and Gonder are dominated by soil acidity (Endalewu *et al.*, 2014, Tessema *et al*., 2008). 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 acidic, 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 acidic) 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 (Harter, 2002), reduction and total failure of crops and deterioration of soil physical properties. In general, it affects the biological, chemical and physical properties of soil, which in turn affects 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. Liming is the major mechanism of ameliorating soil acidity (Omogbohu 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). Liming materials are the most commonly used option to increase soil pH. However, for most efficient crop production on acid soils, application of both lime and fertilizer are required. Even though lime makes 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. Through proper lime and fertilizer management, practices, the quality and productivity of acid soils can be improved. Research attempts are made in the Southern Ethiopia to calibrate the lime correction factor based on exchangeable acidity as well as to determine the rate of phosphorus fertilizer (Ayalew, 2011; Achalu *et al*., 2012). However, the research done by Ayalew, (2011) was not comprehensive and hence there is no lime recommendation in the country. Therefore, the objectives of the present study were (1) to find the correction factor of lime requirement for acidic soils using exchangeable acidity techniques, (2) to evaluate the effect of lime and phosphorous fertilizer on bread wheat yield, and soil chemical properties in northwest Ethiopia, (3) to assess the economical feasibility of lime and phosphorous fertilizer for small scale farmers.

Material and methods

Description of the study area

The research was conducted for two years i.e. in 2011-20112 on farmers' field at Tsegure and Minute kebeles of Farta district, Southern Gondar of the Amhara Regional State. Minute kebele is located 18 km from Gassay on the way to Estie traversed by gravel roads while Tsegure kebele is located around 10.5 km from Debretabur town on the way to Bahir Dar. The study sites were situated within the Lake Tana Basin. According to the Ethiopian agro ecological zonation, the area was categorized under Moist Dega (2300 to 3200 masl with a rainfall ranging from 900 to 1400 mm) with a uni-modal rainfall season.

Table 1. Soil properties of the experimental sites.

location	Initial pH	Exchangeable Al	Exchangeable H	Exchangeable Acidity	Organic matter (%)	Textural class (%)		
						clay	Silt	Sand
Tsegure	5.24	0.16	0.29	0.69	1.88	43	37	20
Minet	5.24	1.02	0.53	1.31	2.17	63	27	10

Experimental setup

Composite soil samples were collected from 0 - 15 cm soil depth and analyzed for exchangeable acidity, pH, organic matter and texture prior to planting. The amount of lime was calculated based on soil mass per hectare at soil depth of 15 cm, soil sample density and exchangeable Al^{+3} as well as H^{+} for each site. The amount of lime applied was calculated based on the following equation.

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

Where: Cmol EA = cent mole of exchangeable acidity of the soil sample (exchangeable aluminum and hydrogen), B.D = bulk density of the soil in mega gram per meter cube

Fixed plots with the following treatments were used for 2 years in randomized complete block design (RCBD)

1. Control (without lime and fertilizer)
2. 138 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1}
3. 2 t ha^{-1} lime+138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}
4. 138 kg N ha^{-1} + 23 kg P_2O_5 ha^{-1} with 1X exchangeable acidity of lime
5. 138 kg N ha^{-1} + 23 kg ha^{-1} with lime by 1.5 X exchangeable acidity
6. 138 kg N ha^{-1} + 46 kg P_2O_5 ha^{-1} with lime by 1X exchangeable acidity
7. 138 kg N ha^{-1} + 46 kg P_2O_5 ha^{-1} with 1.5 X exchangeable acidity of lime

The total amount of lime was applied once in the first year. The lime was applied by broadcasting and incorporated into the soil two weeks before planting. Urea and DAP were used as the sources of fertilizer for N and P respectively. Nitrogen was applied in splits half at planting and half at tillering while all phosphorus was applied at planting. Improved bread wheat variety (TAY) was used as a test crop. Lime was not applied during the second year while the rate of nitrogen and phosphorus were similar to the first year. The amount of lime required based on the extent of soil acidity in the first year (before planting) was indicated in Table 1.

Table 1. Extent of soil acidity and required lime for each sites based on equation 1

location	pH	Ex. Al	EX.H	Ex. Acidity	OM	BD	Textural class (%)			Lime kg ha^{-1}	Lime kg ha^{-1} (1.5x)
							clay	silt	Sand		
Tsegure	5.24	0.16	0.29	0.69	1.88		43	37	20	637	1009
Miynet	5.24	1.02	0.53	1.31	2.17		63	27	10	1277	1916

Economic analysis

To support the biological responses with economic justification, the net present value was used. The return to farmers from wheat production under different lime and phosphorous rates was estimated by net present value (NPV) over the two years. NPV is defined as "present worth of benefits less present cost of a project'' (Vincent et al., 2010; Macharia et al., 2006; Gittinger, 1982). It is mathematically expressed as:

$$NPV = \sum_{t=2}^{n} (B_t - C_t)/(1+i)^t \quad \text{equation 2}$$

Where: $(B_t – C_t)$ = Net Benefits at time t years

$(1 + i)^t$ = Discounting Factor

i = interest rate (%)

Costs of phosphorous fertilizers, lime, Wage for lime and fertilizer application and production prices were collected. The discount rate was taken as the opportunity cost of capital, which is defined as “that rate which will result in the utilization of all capital if all possible investments were undertaken”. Interest rate of capital was taken as 5 percent per year and the time (t) for two years. Different treatments were ranked on basis of their NPV value and those with NPV > 0 were acceptable as economically viable investments. The mean cost of Urea, DAP and lime were, 6.49, 7.67 and 0.85 Ethiopian Birr per kilogram respectively in 2011/2012 and 12.11, 13.91 and 1.55 respectively in 2012/2013. The cost of labor was 40 birr/man/day. The price of wheat was 6.17 Birr in 2011/2013 and 8.36 Birr in 2012/2013.

To make strong economic feasible recommendation incremental benefit analysis was also conducted based on the following equation

$INB^i_j=NB^i_j- NB^i_0$ ………………………………………………………………………… Equation 3

Where:

INB^i_j = the incremental net benefit of option j over the farmer's practice in season (i) in birr ha^{-1}.

NB^i_j =the net benefit of option j, in season i, in birr ha^{-1}.

NB^i_0= the net benefit from the farmer's practice (without any lime and fertilizer) in season i, in birr ha^{-1}.

Results and discussions

Influence of lime and phosphorous fertilizer on yield and yield components of bread wheat

The soil analysis result showed that the two locations were different in exchangeable acidity, organic matter (OM) and texture (Table 1). According to Hazelton and Murph (2007), suitable soil pH for wheat production was 5.5 to 7 (Fenton and Helyar, 2007). The pH of the testing sites was below 5.5 indicating that wheat production was greatly affected by soil acidity. Similarly, the critical aluminum levels extracted by $CaCl_2$ solution for wheat were 0.4 to 0.8 ppm, above which aluminum becomes toxic and affects wheat production (Fenton and Helyar, 2007). The soil analysis result showed that aluminum content of the soil was greater than the critical level at Minet (1.31 ppm) whereas at within the range (0.69 ppm) at Tsegure (Table 1).

Statistical analysis of variance revealed that there was significant variation among the treatments and locations as well as the interactions. Addition of lime equivalent to 150% of the soil exchangeable acidity with 46 kg P_2O_5 ha^{-1} gave the maximum gain yield (Table 2; Table4) in 2012 cropping season. However, there was no significant difference among phosphorus rates at Minet. In the second year the result followed similar trends in grain yield. The maximum grain yield was recorded by applying lime (1.5X) + 46 kg P_2O_5 ha^{-1}. The yield advantage of lime (1.5X) + 46 P_2O_5 kg ha^{-1} over the recommended N and P was 20% (750 kg ha^{-1}) (Table 2). The grain yield was increased by 3290 kg (261%) compared to the control. The result indicates that wheat yield can be improved in acidic soils through the integrated use of chemical fertilizer and lime.

Table 2. Response of wheat grain yield (t ha^{-1}) to lime and P fertilizer at Minet

	Year		
Treatment	2012	2013	Combined
1	1.98^{d}	0.54^{d}	1.26c
2	5.06^{c}	2.06^{bc}	3.80b
3	5.62^{abc}	2.49^{ab}	4.06ab
4	5.39^{bc}	1.92^{c}	3.64b
5	5.83^{ab}	2.26^{bc}	3.82b
6	5.59^{abc}	2.11^{bc}	3.85b
7	6.19^{a}	2.92^{a}	4.55a
CV (%)	7.97	14.83	14.33
LSD (0.05)	0.72	0.54	0.60

Considering the straw yield at Minet, there was significant variation among treatments (Table 3). The maximum straw yield was obtained from lime (1.5 X) + 46 kg P_2O_5 ha^{-1} combined over years (Table 3). However there was no significant difference between using lime (1.5 X) lime (blanket recommendation). Straw yield was increased by 19% using lime (1.5X) + 46 kg P_2O_5 ha^{-1} compared to using recommended fertilizer alone (Table 3). Using no lime and fertilizer resulted in a straw yield penalty of 239%. The result indicates that farmers could reclaim their soils and significantly enhanced the productivity of the crop.

Table 3. Response of straw (t ha^{-1}) to lime and Phosphorous fertilizer at Minet

	Year		
Treatment	2012	2013	Combined
1	3.50^{d}	1.16^{c}	2.33^{d}
2	9.39^{bc}	3.92^{ab}	6.65^{bc}
3	10.28^{ab}	4.56^{a}	7.42^{ab}
4	9.30^{bc}	3.53^{b}	6.42^{bc}
5	8.55^{c}	3.99^{ab}	6.27^{c}
6	110.24ab	4.57^{a}	7.40^{ab}
7	11.17^{a}	4.60^{a}	7.89^{a}
CV (%)	7.48	22.68	18.54
LSD (0.05)	0.60	0.77	0.70

Similarly, there was significant difference among treatments for grain and straw yields at Tsegure (Table 4; Table 5). The highest grain yield was obtained from lime (1.5X) + 46 kg P_2O_5 ha^{-1} combined over years. A grain yield advantage of 1190 kg ha^{-1} (125 %) was observed from lime (1.5X) + 46 kg P_2O_5 ha^{-1} compared to the control. Likewise, 560 kg ha^{-1} (35%) grain yield advantage was obtained from lime (1.5X) + 46 kg P_2O_5 ha^{-1} compared to the recommended NP alone (Table 4).

Table 4. Response of grain yield (t ha^{-1}) to lime and P fertilizer at Tsegure

	Yield		
Treatments	2012	2013	Combined
1	1.39^{d}	0.42^{d}	0.95^{c}
2	2.74^{c}	0.49^{cd}	1.58^{b}
3	3.05^{bc}	0.73^{b}	1.82^{ab}
4	3.01^{bc}	0.61^{bc}	1.83^{ab}
5	3.09^{abc}	0.65^{b}	1.73^{ab}
6	3.40^{a}	0.60^{bc}	1.79^{ab}
7	3.24^{ab}	1.04^{a}	2.14^{a}
CV (%)	7.04	11.80	22.50
LSD (0.05)	0.36		0.45

The maximum straw yield was recorded from lime (1.5X) + 46 kg P_2O_5 ha^{-1} while the lower was from the control at Tsegure (Table 5). There was 169% straw yield advantages by lime (1.5X) + 46 kg P_2O_5 ha^{-1} over recommended NP alone and 269% straw yield (very toxic and hinders crop growth) was lowered from 1.02 cm mole kg^{-1} of soil to 0 due to lime application at Minet. Similarly, at Tsegure, soil pH was increased from 5.24 to 5.75 and exchangeable acidity was reduced from 0.81to 0.71 due to lime (Table 6). Exchangeable aluminum concentration was lower than exchangeable hydrogen at Tsegure and could not be toxic to crop. It becomes zero after lime application and hence the effect on crop yield may rather be from hydrogen.

In general, application of lime increased soil pH and reduced exchangeable aluminum and hydrogen and increased grain and biomass yield of wheat. According to the present study, the significant improvement of soil pH and exchangeable acidity was due to high rate of lime in Minet. The amount of lime required in Minet was doubled as compared to Tsegure due to varied soil buffering capacity of the two (Table 1). Soil buffering capacity governs the amount of lime required and it is governed by soil texture, cation exchange capacity and organic matter content. The soil textural class of the study sites was 63% clay. The exchangeable aluminum concentration of the soil was very high and organic matter content was better at Minet than Tsegure which might increased lime requirement.

Table 6. Extent of soil acidity at harvest in 2012

		Minet		
Treatment	pH	Ex. Al	Ex. H	Ex. Acidity
1	5.24	1.02	0.53	1.31
2	5.28	1.02	0.90	1.92
3	5. 77	0	0.71	0.71
4	5.40	0	0.71	0.71
5	5.77	0.07	0.75	0.82
6	5.66	0	0.71	0.71
7	5.73	0	0.71	0.71
		Tsegure		
Treatment	pH	Ex. Al	Ex. H	Ex. Acidity
1	5.24	0.29	0.75	0.81
2	5.23	0.30	0.73	0.76
3	5.75	0	0.71	0.71
4	5.72	0	0.71	0.71
5	5.71	0	0.71	0.71
6	5.72	0	0.71	0.71
7	5.68	0	0.71	0.71

Economic analysis

NPV was positive for all tested treatments except the control at Minet and Tsegure (Table 7).

Table 7. Net present value and benefit analysis for lime and phosphorous fertilizer rate at Minet and Tsegure

Treatments	Location					
	Minet			Tsegure		
	NPV	INB	Rank	NPV	INB	Rank
1	0.00	0.00	7	0.00	0.00	7
2	684.43	24639.40	6	51.20	1843.30	5
3	819.71	29509.40	3	30.40	1094.40	6
4	689.08	24806.85	5	105.95	3814.15	4
5	823.91	29660.90	2	109.42	3939.00	3
6	749.25	26973.05	4	152.24	5480.65	2
7	1019.2	36692.50	1	206.05	7417.70	1

For all the study sites the NPV of lime and phosphorus application showed a positive value leading to rejection of null hypothesis (H_0) that lime technologies are less cost-efficient to enhance soil fertility, crop yields and finally livelihoods within short time (Table 7). Accordingly these results suggested that all treatments at Minet and Tsegure are economically feasible as the NPVs are greater than zero (NPV > 0). Maximum NPV (1019.2 Birr) with incremental benefit (36692.5 Birr) was obtained from lime (1.5X) + 46 kg P_2O_5 ha^{-1} at Minet while the lower NPV was obtained from the control (Table 7). The second highest NPV (823.91 Birr) with incremental benefit (29660.9 Birr) was obtained from lime (1.5X) + 23 kg P_2O_5 ha^{-1}. Similarly, at Tsegure, the highest NPV (206.05 Birr) with an incremental net benefit (7417.7 Birr) was obtained from lime (1.5X) + 46 kg P_2O_5 ha^{-1}while the second highest NPV (152.24 Birr) with incremental benefit (548.65 Birr) was obtained from lime (1X) + 46 kg P_2O_5 ha^{-1} (Table 7). The result is inconformity with the findings of Macharia *et al.,* (2006). The difference in NPV and incremental benefit between the study sites was related to the soil fertility status of the sites. Minet site has better fertility status compared to Tsegure site which is highly degraded.

Conclusion and recommendation

From the biological yield, soil and economic analysis results, it is possible to conclude that the liming factor is 1.5 times the exchangeable acidity. The result also confirmed that lime has great influence on grain and straw yield as well as improving chemical soil properties. The improvement in yield and economic return due to lime and phosphorous fertilizer in acidic soils of the west Amhara highlands is appreciable. However, farmers' knowledge on the effect of lime on soil properties, how to use lime to reclaim acidic soils, source of lime and the like should be upgraded. The policy makers should take the lead in availing lime in required amount to the farm gate so that the farmers can get it easily with affordable price.

Therefore, from the result, it is possible to recommend lime amount determined using 1.5X exchangeable acidity can be used as correction factor for lime calculation using exchangeable acidity. This finding should be further refined for different soil types and agro-ecologies. The calcium carbonate equivalency and finesse of Ethiopian liming materials should be studied. Fertilizer rate studies for acidic soils should also be integrated with lime.

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