Evaluation of Row Application of Lime for Bread Wheat on Acidic Soils of Wadla District, North Wollo, Ethiopia

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Abstract

Soil acidity is one of the major challenging issues adversely affecting sustainable crop production in Ethiopia in general and in Wadla district in particular. Acidic soils are deficient in essential plant nutrients. Furthermore, soil acidity affects root development leading to reduced nutrient and water uptake. Hence, a field experiment was conducted in 2017/18 and 2018/19 main cropping seasons to evaluate the effect of row application of lime on yield and yield components of bread wheat in acidic soil of Wwadla district using calcium hydro oxide direct titration method. The actual lime requirement was splinted in to 12.5, 25, 50 and 75% to be applied in row. The experiment was comprised of sixtreatments including: control (without input), recommended nitrogen and phosphorus only, and four levels of lime rates (12.5, 25, 50 and 75%) with recommended NP and was lieddown in randomized complete block design with three replications. The collected data on yield and yield-related parameters were analyzed using SAS, version 9.1 and subjected to Duncan's Multiple Range Test for mean separation when the analysis of variance was significant. The over year combined analysis of an experiment showed no significant (P ≥0.05) yield difference among lime rate and recommended NP, except when compared with the control treatment that has no lime and recommended NP. The partial budget analysis result revealed that application of 50% of the actual lime rate in row application brought economically optimum grain yield. So application of 50% of lime could be recommended in the study area.

Keywords: *Lime, Row application, Soil acidity, Wheat*

Introduction

Wheat (*Triticum aestivum* L.) is one of the major global cereal crops, ranking second after paddy rice both in area coverage and production, and provides more nourishment than any other food crop (Curtis, 2002). Wheat provides more protein than any other cereal crops (Hussein *et al*., 2006). It is a major source of energy and proteins for population inhabiting most highlands in Ethiopia (Abera Bekele, 1991). Bread wheat in Ethiopia stands fourth in both area coverage and total annual production, and second in yield per hectare next to maize (CSA, 2017).

Ethiopia is the leading Sub-Saharan Africa economy depends on smallholder farm agriculture. The contribution of the agricultural sector to Gross Domestic Product (GDP) is large (41%); 85% of the employment opportunity, 90% of the export level, and provides 70% of the country 's raw material demand of the large and medium scale industries found from this promising sector (MoFED, 2012). Nevertheless, around 29% of its population yet is living under poverty (World Bank, 2014). production and productivity of the agricultural sector in Sub-Saharan Africa is low due to low technological adoption and techniques among others (Binju Abraham *et al*., 2014; Berihun Kassa *et al*., 2014).

Most wheat producing area in Ethiopia lie between 6^o and 16^o N latitude and 35^o and 42^o E longitudes of an altitude range from 1500 to 3000 meters above sea level (m.a.s.l) (Amare Assefa and Mulatu Kassaye, 2017). The most suitable agro-ecological zones, however, fall between 1900 to 2700 meters above sea level (Bekele *et al*., 2000). Currently, Oromia,

the major wheat producing areas in Ethiopia. Wheat is grown annually on 1.66 million hectare of land in Ethiopia with a total production of 4.23 million tons with an average productivity of 2.54 t ha^{-1} which makes the country the second largest wheat producers in sub-Saharan Africa. Amhara National Regional State is among the most important wheat growing areas of the country. The production and area Coverage of wheat in Amhara Region is 0.55 million hectare of land with the total production 1.22 million tons with an average productivity of 2.24 t ha^{-1}. The area Coverage and production of wheat in North Wollo is 32,005.82 hectares 0.474 million tons with the average productivity is 1.5 t ha^{-1} (CSA, 2016). However, its

Furthermore, wheat has been selected as one of the target crops in the strategic goal of attaining national food self-sufficiency, income generation, poverty alleviation and achieving socio-economic growth of the county (Mulatu Kassaye, 2015).

Soil acidification is a complex process resulting in the formation of an acid soil due to excessive concentration of non-soluble and toxic ions in the soil solution (Jafer Dawid and Gebresilassie Hailu, 2017). The process of acidification results the replacement of basic cations Ca, Mg and K in the soil exchange sites with Al, Mn and Fe and increased the concentration of H^+ ion in the soil solution. This condition also usually leads to Al and Mn toxicity plus deficiency in N, P, K, Mg, Ca and various micronutrients. Where soil pH is lower than optimal (5.5 and below) the availability of nutrients needed for growth is reduced (Jafer Dawid and Gebresilassie Hailu, 2017). Soil acidity and nutrient depletion, particularly of nitrogen (N), phosphorus (P) and low soil organic matter are some of the constraints limiting agricultural production in the high rainfall areas (Opala *et al.*, 2010; Kisinyo, 2011). High soil acidity found in the high land area is associated with aluminum, hydrogen, iron and

magnesium and potassium (Sanchez *et al*., 1997).

A major challenge to cereal crop production in the highlands of Ethiopia is low soil pH and associated with low fertilizer application and soil fertility problems. Low soil pH reduces plant availability of several nutrients, increases levels of some elements to phytotoxic concentrations (i.e., Al^{3+}
(Brady, 1990; Merino *et al.*, 2010). These poor growth conditions can lead to reductions in root development which consequently causes slow vegetative growth and low total biomass per unit area. Application of lime is no doubt the best alternative to alleviate topsoil acidic problem and provide conditions for adequate crop development.

Soil acidity and Al^{3+} toxicity in surface soil can be ameliorated through liming (Fegeria and Baligar, 2008; Haling *et al*., 2010). Changes in soil pH brought about by liming may have profound effects on the availability of many elements absorbed by crops. Liming increases soil pH and thus decreases Al^{3+} and Mn toxicities which also increase NO^{3-}N, Ca and P availability (Arshad and Gill, 1996; Caires *et al*., 2005). One of the challenge facing farmers in liming is the requirement of huge amount of lime to rise the pH of the soil. To alleviate this challenge row application of lime is todays serious issue. A lot of efforts were done to improve acid soils of Ethiopian highlands. Among those developed technologies, split lime application from the actual requirement determined by ¼ (EAx1.5) is economical and applicable to farmers developed by (Asmamaw Demil et *al*., 2020). Therefore, this proposal is initiated to evaluate row application of lime for bread wheat for specific areas of Wadla.

Materials and Methods

Site Description: The study was conducted in 2017/18 and 2018/19 main cropping seasons in Wadla district of North Wollo zone of the Amhara Region. The district is situated in a geographica -2800 meters above sea level. The district receives a mean annual rainfall of 800-1200 mm with

Geology of the Study Area: The geology of Eastern Amhara including the study area is covered by Cenozoic volcanic rocks with some sedimentary rocks (Kogan *et al*., 2012). The major formations are Ashangi, Tarmaber-Megezez, Alajae, Aiba basalts and Amba-Aradom formations covering 49, 18, 14, 12 and 3%, respectively (Mengesha Tefera *et al*., 1996). The geology of the study area belongs to Tarmaber-Megezez formations. Tarmaber-Megezez formations are transitional and alkaline basalts (Mengesha Tefera *et al*., 1996). According to FAO (1984) the soils of Wollo area have been developed almost exclusively on Trap Series volcanoes.

Experimental Procedures

Selection of farmers' fields and lime estimation methods

Soil samples at a depth of 0-20 cm were collected from ten farmers' fields in 2017/18 and 2018/19 prior to the start of the experiment. Based on the soil pH (1:2.5 soil: water suspension) results, five farmers' fields in 2017/18 and four farmers' fields in 2018/19 were selected to condect the experiment.

$CaOH_2$ direct titration method (Abebe Getu *et al.*, 2020) was used to calculate the actual requirement of lime for each site (Equation 1). Different rate of lime was calculated based 12.5, 25, 50, and 75% for each site from the actual requirement of lime (Equation 2).

LR ($kgha^{-1}$) = based on $Ca(OH)_2$ titration method with scatter plot graph

Equation (2)

Where **LR**=lime requirement in kg ha^{-1} , **Y%**=rate of Lime (0 12.5, 50 and 75%)

The experimental design was randomized complete block design (RCBD) with 3 replications for each site. The plots size was 5 x 4m. Recommended rate of 69 N and 69 P_2O_5 kg ha^{-1} fertilizers for wheat was applied using urea and NPS sources respectively**.** Half of N was applied at planting and the remaining N was applied at tillering in the form of split application. Full dose of P_2 O_5 was applied at planting only. The seed was drilled in rows and the space between rows was 20cm apart.

Treatments

1. Control (0)
2. 64/69 N/P_2O_5
3. 12.5% Lime+64/69 N/P2O5
4. 25.0% Lime+64/69N/P_2O_5
5. 50.0% Lime+64/69 N/P_2O_5
6. 75.0% Lime+64/69 N/P_2O_5

Data Collected

Soil data collection: Before planting, the soil samples were collected from representative experimental plots after the removal of plant litter and any other material from the soil surface. Then,the soil samples were collected in a zigzag pattern to a depth of 0-20cm using soil auger. Each of the soil samples from collected from the expermenrtal plots were bulked to make a single one kilogram composite soil sample. The pH of the soils was measured in water suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 1992). Total nitrogen (N) was determined using the micro-Kjeldahl digestion, distillation and titration procedure as described by Bremner (1996). Available P was extracted by the Bray-II method using 0.03 M·NH_4F and 0.1 M·HCl solution (Bray and Kurtz, 1945). The organic carbon content of the soil was analyzed by following the wet digestion method and percent soil OM was calculated by multiplying percent soil OC by a factor of 1.724 following the assumptions that OM is composed of 58% carbon as described by Van Reeuwijk (1992). Exchangeable Al in the soil samples was determined by application of 1M NaF which form a complex with Al and released NaOH and then NaOH was back titrated with a standard solution of 0.02M HCl. In preparation for laboratory analysis, the soil samples were air dried, crushed and made to pass through a 2mm sieve for the analysis of soil pH, soil texture, available P and exchangeable acidity and pass through 0.5mm sieve for the analysis of soil organic matter (OM) and Total nitrogen.

Agronomic Data: Above ground biomass: It was measured by taking the weight of the above ground biomass of plants in a plot at maturity and converted to kg per hectare.

Grain yield: was measured by taking the weight of the grains for plants in a plot at harvest and converted to kg per hectare after adjusting the grain to 12.5% moisture content.

Socio economic data: cost of input and application (lime, fertilizer and labor) and output (grain yield and straw yield) price for partial budget analysis were taken

Statistical analysis: The agronomic data variation across each level of treatment/each plot was analyzed using Analysis of Variance (ANOVA) using SAS (Version 9.1). Mean separation was done using Duncun multiple range test at 5% probability level. Partial budget analysis was done according to CIMMYT (1988).

Results and Discussion

Selected Physico-chemical Property of the Soil

The soils of experimental sites were characterized for selected physico-chemical properties before the application of treatments as shown (Table 1.1). The result indicated that the textural classes of experimental sites were silty clayloam, clay, clayloam and siltyclay (Table 1). The average soil pH value of the experimental sites ranged from 4.58-5.24 which is categorized under strongly acid (Tekalign Tadesse, 1991). The soil total nitrogen ranged from 0.024-0.053% and OC 2.09-3.42% was found to be low and medium to high (Tekalign

Tadesse, 1991), respectively. The available phosphorus content of the experimental site was 10.91-20.68 mg kg^{-1}. According to Jones (2003) available soil P (Bray II method) level was rated as low to medium. This may be attributed to the absence of exchangeable Al (Table 1) in the study area.

Table 1. Selected soil property of the experimental site at planting in 2018 cropping season

Farms name	pH	OM	TN (%)	AV. P(ppm)	Exch.Al^{+3} (meq/100g soil)	Exch.H^{+}(meq/100g soil)	Textural Class
Farm 1	5.08	2.09	0.053	10.91	0	3.6	Silt clay loam
Farm 2	4.84	3.42	0.025	20.30	0	5.2	Clay
Farm 3	4.58	2.17	0.024	14.77	0	4.9	Silt clay
Farm 4	4.98	2.86	0.024	15.91	0	4.5	Clay loam
Farm 5	5.24	3.33	0.027	20.68	0	3.9	Silt clay

Effect of lime application on Bread Wheat Grain Yield

significant grain yield over the recommended nitrogen and phosphorus fertilizer, but it is significantly higher from control (Table 2). The lowest grain yield (1546.1 kg ha^{-1}) was obtained from control while, application of 75% lime gave better grain yield (64.7%) over the control (Table 2).

In the second year (2019), significantly higher grain yield were observed in the aplication of different rate of lime and recommended NP alone than the control treatment (Table 4). As indicated in Table 3 the highest grain yield was obtained in the application of 50% lime rate which is not stastically different from other lime rate and recommended NP alone. But stastically lowest grain yield were obtained from control (2195.3 kg ha^{-1}).

The over year combined analysis (2018 and 2019) of an experiment showed no significant (P

the control treatment that has no lime and recommended NP (Table 6). Based on the combined analysis result (two years result) the highest grain yield (2794 kg ha ^{1}) was observed in 50% lime rate, which was statistically similar to 25%, 75% lime rate and RNP alone whereas the lowest value (1834 kg ha ^{1}) was recorded in control (Table 6). Our results demonstrated that the application of lime and RNP significantly improved grian yield of wheat than the control.

The findings are in agreement with Athanase (2013) liming is an important practice to achieve optimum yields of all crops grown on acid soils. These grain yield result increment agreed with Shiferaw Boke and Anteneh Fekadu, (2014) application of lime alone or combined with fertilizers significantly increased barley yield over untreated control. Abreha Kidanemariam *et al*., (2013) also confirmed that combined application of lime and NP fertilizers are recommended to achieve sustainable wheat crop production on acidic soils of the Tsegede highlands. In addition Tadesse Moges *et al*., **(**2018**)** stated that application of lime with P fertilizers increased the grain yield of malt barley up to 91.6% compared with the control and Temesgen Desalegn *et al*., (2017) also confirmed that combined applications lime and P fertilizer gave 133% more grain yields of barley relative to control (without P and lime).

Asmamaw Demil, *et al* (2020), revealed that application of lime at a 25% rate based on exchangeable acidity in rows at planting significantly increased the grain yield of wheat (4525 kg ha ^{1}) in the acidic areas. On the other hand this result was dis agreed with the findings of Wanjiru, (2018) who stated that lime plus fertilizer had higher grain yields than the sole fertilizer treatment.

Effect of lime application on Bread Wheat Biomass Yield

Biomass yields of wheat responded significantly to the different rates of lime and recommended NP rate (Table 3, 5 and 6). The highest biomass yield of 6786.8 kg ha^{-1}, 8379.8 kg ha^{-1} and 7471.2 kg ha^{-1} was obtained from the application of 75% lime rate during 2018, 25% lime rate during 2019 and 50% lime rate (combined years) but not significantly different from other lime rate and recommended NP. In addition the lowest value of biomass yield was noted in control in both cropping years and also in the combined analysis (Table 3, 5 and 6).

This result in line with the study of Tadesse Moges *et al*., (2018) who confirmed that the lowest total yiomass yield (6.05 ton/ha) was recorded in the treatment without lime and application of lime increased Biomass Yield by 16.53% - 22.59%, as compared to the control. Shiferaw Boke and Anteneh Fekadu (2014) also stated that biomass yield of barley was significantly improved by application of lime and fertilizers alone.

Table 2. Effect of lime rate on wheat yield (kgha-1) in 2018 at Alpha value 0.05

Treatments	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Combined
Control (0,0)	1503.9^{c}	1886.1^{bc}	1412.1^{d}	2100.8^{c}	827.5^{b}	1546.1^{b}
RNP	2294^{b}	2343.3^{b}	2167.1^{bc}	2325.8^{bc}	1269.5^{ab}	2065.6^{a}
12.5% lime	2598.4^{ab}	2515.4^{ab}	1998.5^{c}	3434.1^{a}	1470.6^{a}	2403.4^{a}
25% lime	2356.8^{ab}	2913.4^{a}	2411^{ab}	2910.5^{abc}	1383.4^{a}	2395.0^{a}
50% lime	2853.7^{a}	2726.1^{ab}	2463.6^{a}	3253.1^{ab}	1237.9^{ab}	2506.9^{a}
75% lime	2813.9^{ab}	2836.4^{ab}	2532.6^{a}	2844.8^{abc}	1707.5^{a}	2547.1^{a}
CV(%)	11.50	11.3	5.9	13.9	14.5	17.4

Table 3. Effect of lime rate on wheat biomass (kgha-1) in 2018 at at Alpha value 0.05

Treatments	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Combined
Control (0,0)	3892.6^{c} bb489	4739.1^{b}	3681.2^{c}	5391^{c}	2202.9^{b}	3981.4^{b}
RNP	6408.4^{b}	6449.3^{a}	5847.8^{b}	6203^{bc}	3391.3^{ab}	5625.3^{a}
12.5% lime	7176.5^{ab}	6478.3^{a}	5884.1^{b}	8725^{ab}	3869.6^{a}	6426.6^{a}
25% lime	6737.8^{ab}	7420.3^{a}	6811.6^{a}	7580^{abc}	3956.5^{a}	6501.2^{a}
50% lime	7868.9^{a}	6594.2^{a}	7000^{a}	9072^{a}	3289.9^{ab}	6765.1^{a}
75% lime	7600.8^{ab}	7405.8^{a}	7029^{a}	7406^{abc}	4492.8^{a}	6786.8^{a}
CV(%)	9.3	12.6	5.8	14.9	12.7	16.3

Table 4. Effect of lime rate on wheat yield (kg ha^{-1}) in 2019 at Alpha value of 0.05

Treatments	Farm 1	Farm 2	Farm 3	Farm 4	Combine
Control (0,0)	1992.0^{b}	2183.0^{c}	1680.8^{b}	2925.5^{b}	2195.3^{b}
RNP	2730.9^{ab}	3045.1^{ab}	2571.3^{a}	3924.0^{a}	3067.8^{a}
12.5% lime	2568.3^{ab}	3371.6^{a}	2142.8^{ab}	3719.2^{a}	2950.5^{a}
25% lime	2932.8^{a}	3272.4^{ab}	2385.3^{a}	3631.5^{a}	3055.5^{a}
50% lime	3270.3^{a}	2966.6^{b}	2717.4^{a}	3658.4^{a}	3153.2^{a}
75% lime	2630.9^{ab}	3155.3^{ab}	2667.4^{a}	3847.9^{a}	3075.3^{a}
CV(%)	15.85	7.05	15.29	9.02	18.18

Table 5. Effect of lime rate on wheat biomass (kgha-1) in 2019 at Alpha value of 0.05

Treatments	Farm 1	Farm 2	Farm 3	Farm 4	Combine
Control (0,0)	5347.8^{b}	5695.7^{b}	4631.6^{b}	7174.6^{b}	5712.4^{b}
RNP	7710.1^{a}	8855.1^{a}	6982.5^{a}	9619.0^{a}	8291.7^{a}
12.5% lime	7289.9^{ab}	9391.3^{a}	6087.7^{ab}	9825.4^{a}	8148.6^{a}
25% lime	8058.0^{a}	9043.5^{a}	6719.3^{a}	9698.4^{a}	8379.8^{a}
50% lime	9115.9^{a}	8289.9^{a}	6929.8^{a}	9079.4^{a}	8353.7^{a}
75% lime	7043.5^{ab}	8637.7^{a}	7175.4^{a}	9761.9^{a}	8154.6^{a}
CV(%)	16.20	9.02	15.40	5.60	17.74

Table 6. Effect of lime rate on grain and biomass yield combined over the two years

Treatments	Grain yield(kgha-1)	Biomass yield(kgha-1)	Grain yield excluding (0,0)
Control			
RNP			
12.5% lime			
25% lime			
50% lime			
75% lime			
CV(%)			

Partial Budget Analysis: The partial budget analysis for marginal rate of return Table 3.7 showed that the recommended NP and row application of lime gave acceptable marginal rate of return (*i.e.,* MRR greater than 100%). According to CIMMYT (1988) when there are two and more treatments with MRR greater than 100%, the treatment with greater net benefit should be selected for recommendation. Therefore, row application of 50% of lime brought the maximum net benefit (51894.9 Ethiopian Birr) per hectare while possessing MRR of greater than 100% and thus it is economically feasible for Wadla district.

Table 7. Partial budget analysis of the variable costs on mean grain and straw yields of wheat in Wadla district for lime rate

Treatments	AGY*	GYP	ASY	SYP	TR	FC	TFC	L	LiC	TLiC	LC	TVC	NB	MRR
Control (0,0)	1651.5	20	2624.6	2	38271.96	14	0	0	0	0	0	0	38272.0	
RNP (69,69)	2277.1	20	3898.7	2	53339.22	14	4200	0	0	0	1000	5200	48139.2	1.90
12.5% lime + RNP	2381.9	20	4090.1	2	55818.9	14	4200	205.9	0.75	154.4	1600	5954.4	49864.5	2.29
25% lime + RNP	2419.8	20	4182.8	2	56760.3	14	4200	411	0.75	308.3	1800	6308.3	50452.1	1.66
50% lime + RNP	2514.7	20	4209.4	2	58712.58	14	4200	823.6	0.75	617.7	2000	6817.7	51894.9	2.83
75% lime + RNP	2503.6	20	4151.6	2	58375.62	14	4200	1235.4	0.75	926.6	2400	7526.6	50849.1	D

* *AGY=Adjusted grain yield (kgha^{-1}), GYP=Grain yield price/kg (ETB), ASY= Adjusted straw yield, SYP=Straw yield price, TR=Total revenue, FC=fertilizer cost/kg (ETB kg^{-1}), TFC total fertilizer cost (ETB), L=lime amount (Kg ha^{-1}), LiC= lime cost/kg (ETB), TliC= Total lime cos, LC= lime cost, TVC= total cost, NB= Net benefit, MRR= Marginal rate of return (%)*

Conclusion and Recommendation

Acid soils can be made productive by applying lime in different parts of the country as well as in the Amhara region. In addition to lime, application of recommended nitrogen and phosphorus fertilizer gives equivalent yield with application of different rate of lime in the district. As it is observed from the result row application of lime couldn't brought statistically significant biological yield difference compared to the recommended NP rate. But the partial budget analysis result revealed that application of 50% of the actual lime rate in row application brought economically optimum grain yield. So application of 50% of lime could be recommended in the study area. Further research investigation on the long term indirect impact of lime (availability of micro nutrients, decomposition of residue in to

in the acidic soil of Wadla district should be conducted.

Acknowledgements

The authors are grateful to Amhara Regional Agricultural Research Institute for covering the research fund. Many thanks to Sirinka Agricultural Research Center soil and water management researchers, who devoted much of their valuable time on this work.

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