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Research Paper

Lime Application for Acid Soil Amelioration and Improving the Productivity of Barley in Semen Ari District, Southwestern Ethiopia

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Abstract

Soil infertility constraints and low soil pH are the predominant problems to barley production and productivity in the highland regions of Ethiopia. In reaction to this, the experiment was carried out in highland areas of Semen Ari district with low soil pH to determine the effects of split application of lime on soil pH and grain yield of barley from 2018 to 2020 for three cropping years. Six treatments were used for this experiment as control (no inputs); 200 kg ha^{-1} of NPKSZnB + 94 kg ha^{-1} of urea top-dressed; lime applied at once (7.6 t ha^{-1}); two splits or 50% (1st and 2nd years); three splits or 33% (1st, 2nd and 3rd years); two splits or 50% (1st and 3rd years). The RCBD design within three replications was employed to arrange treatments. The result of soil analysis after lime application revealed that it improved available phosphorus and raised the soil pH, but decreased the exchangeable acidity compared to control treatments. Among the treatments, lime application in two splits (1st and 3rd years) gave the maximum grain yield (3061.5 kg ha^{-1}) of barley significantly, whereas the minimum yield was obtained from the control (untreated plot). The maximum grain yield in the third year was obtained from the application of two splits or 50% (1st and 3rd years) which were statistically non-significant with the application of three splits or 33% in each year (1st, 2nd and 3rd years) and two splits or 50% (1st and 2nd years). Thus, to enhance soil fertility status and obtain better barley grain yield, farmers must undertake the use of a split application of lime with inorganic fertilizer rather than a sole application of inorganic fertilizer. It suggested that, depending on the accessibility of lime and affordability of barley producers, farmers in the study area could use the above application frequencies with recommended inorganic fertilizers (69N and 46P_2O_5). Further investigation should be done on plant nutrient uptake, nutrient use efficiency and optimization.

1. Introduction

Soil fertility problem is a serious issue in agricultural production and productivity in many regions of Ethiopia. It is characterized by plant nutrient deficiencies and toxicities, reduced plant root growth, hindering activities of important microorganisms, and restricting the absorption of nutrients and water by plants (Fegeria and Baligar, 2008). Soil acidity and Al^{3+} toxicity might be improved through liming (Rebecca *et al*., 2010). Modifications can be carried out by limiting soil pH which profoundly affects the availability of many nutrients utilized by crops. Lime applied on acidic soils raises the pH and consequently reduces the concentration of toxicities of Al^{3+} and Mn, increasing the availability of plant nutrients (Caires *et al*., 2005).

Highland areas of Ethiopia, with altitudes of >1500 m situated in almost all regional states suffer from soil acidity. According to Ethiosis (2014) report,

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approximately 43% of the fertile soil of the country is influenced by soil acidity. Further, Mesfin (2007) pronounced that soils with a pH of less than 5.5 prominently affect crop development and desire intervention. In Ethiopia, the major factors to increase soil acidity is one of the climatic elements such as the high amount of rainfall, temperature, and morphological and anthropological factors (Ejersa, 2021).

In the highlands of Ethiopia, Barley is one of the leading cereal plants broadly cultivated by small-scale farmers in rain-fed situations. It ranked third cereal crop after teff and wheat in mid-altitude and primary in high-altitude regions (CSA, 2018), it covers 13% of cereals. In the highland area, there are several barley production constraints among them the fertility problem takes the greatest proportion. The world average productivity of barley in 2018/19 is 2.89 t ha^{-1} (Dukhnytskyi, 2019). Barley in Ethiopia occupies about 811,782.08 hectares of land annually with an estimated production of 48,380,740.91 quintals (CSA, 2019). The average yield of barley in the country is lower (2.18 t ha^{-1}), compared to the world average (2.89 t ha^{-1}) and its potential yield of 6 t ha^{-1}. The countrywide mean barley yield is generally reduced with an average of 2.18 t ha^{-1} (CSA, 2019) due to low soil productivity. The application of calcium carbonate ($CaCO_3$) is one of the primary management practices to address when the phosphorus fixation in acid soils is raised (Alemayehu *et al.*, 2017). On the other hand, management practices of acidic soils may vary with the severity of acidity, type of soil, type of farming practices, and socioeconomic condition of the farmers. Liming is a major and effective practice to overcome soil acidity constraints and improve crop production on acidic soils. Therefore, the split application of lime to acid soils is infrequently used in Ethiopia.

Application of appropriate and sufficient amounts of lime with recommended chemical fertilizer is a crucial method for enhancing crop growth in acid soils. On the other hand, there is an information scarcity on the integrated application of lime, organic, and chemical fertilizer utility on crop growth and development in acidic soils of southwestern Ethiopia. The aim of the study was, to examine the effect of split application of lime on some selected soil chemical properties and barely grain yield under acid soil situations in southwestern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area.

The field experiment was carried out for three consecutive years (2018 - 2020) under acidic soils in the Semen Ari district of Southwestern Ethiopia. The experimental site is geographically situated at an altitude of 2804 m.a.s.l and with a place of 05°46’46.9’’ N latitude and 036°33’17.9’’ E longitude. It is located in the southwestern direction at a distance of 96 km from Jinka town. The experimental area has a bi-modal rainfall pattern with an extended rainy season from August to November and a shorter rainy season from March to July. During the major cropping season, the annual rainfall in the study area was 1698 mm, and the mean annual minimum, and maximum temperatures and the mean annual temperatures were 17.32, 27.97 and 22.65°C, respectively. The major crops grown in the study areas are cereals (maize and sorghum), pulse and oil crops (common bean and groundnut), root and tuber (Enset, taro, sweet potato, cassava, and yam), fruits (avocado, banana, mango, and papaya), coffee and spices (coffee, cardamom, ginger, and turmeric) and vegetables.

2.2. Experimental Layout, Design, & Treatments.

Randomized complete block design (RCBD) was used for the experimental area with three replications. The gross size of the plot was 4 m x 4 m (16 m^2), it contained twenty rows from which the central fifteen rows (3 m x 4 m) were used for the collection of data. The spacing between blocks and plots becomes 1 m and 0.5 m, respectively. Row spacing is also 20 cm and sown by drilling with a 150 kg ha^{-1} seed rate. HB 1307, a well-adapted food barley variety in the experimental site was used. Six treatments were used for this experiment such as control (no inputs), 200 kg ha^{-1} NPKSZnB + 94 kg ha^{-1} urea top-dressed, lime applied at once (7.6 t ha^{-1}) during the first cropping season, two splits (50% applied in the first year and the remaining half applied in next cropping season), three splits (33% applied in each year), and two splits (50% applied in the first year and the remaining half applied in the third year cropping season). Before one month of planting, lime was homogeneously broadcasted by hand in the experimental plot and incorporated into the soil. Triple super phosphate (TSP) and urea were used as chemical fertilizer sources and applied in all lime-applied treatments. The half dose of N rate (23N kg ha^{-1}) and a full dose of TSP ($46P_2O_5$) were applied at planting, and half N rate (23N kg ha^{-1}) became side dressed at the tillering stage of barley. The experimental site was cultivated three times before planting and was leveled into blocks and then divided into plots. The applied lime plots were kept permanent for the study site to examine the carry-over effects. Lime requirement in the field was determined based on exchangeable acidity as follows:

$$LR = \frac{LR, CaCO3\ (\frac{kg}{ha}) = \frac{cmolEA}{kg}\text{ of soil } * 0.15m * 104 * m2 * BD\left(\frac{Mg}{m3}\right) * 1000 * 1.5}{2000}$$

2.3. Soil Sampling and Analysis

Initially, a composite soil sample was collected before lime application from the experimental field and subjected to decide lime requirement and also analyses of some soil acidity indicators and other soil physicochemical properties. From the study site, composite samples before planting and from each plot after harvesting were randomly collected from 0-20 cm soil depth using an auger from ten and five spots respectively. The collected samples were ground and air-dried to pass 2 mm sieves, prepared, and analyzed for texture, bulk density, soil pH, available P, total nitrogen, organic carbon, and exchangeable acidity.

Particle size distribution was analyzed using the Bouyoucos hydrometer method as outlined by Bouyoucos (1962). The Kjeldahl procedure (Jackson, 1956) was used to determine total soil N. The pH of the soils was measured potentiometrically and it was measured in water suspension in a 1:2.5 (soil: water ratio) (Van Reeuwijk, 2002). The wet digestion method was used to determine soil organic carbon (OC) content (Walkley and Black, 1934). Bray method II was used to determine available soil P and measured by spectrophotometer (Bray and Kurtz, 1945). According to Mclean, (1965), the exchangeable acidity was determined by saturating the samples with potassium chloride solution with sodium hydroxide titration.

2.4. Data Collection

During the experimental period, the number of tillers, spike length, plant height, number of seeds per spike, 1000 seed weights, grain yield, and above-ground biomass data were recorded. From the central rows, the plant heights were measured at physiological maturity. From the randomly selected ten plants in each plot, the average values were recorded and determined as the plant height. For thousand seed weight (g): from each plot sun-dried 1000 seeds were randomly taken from the seed lots, counted by seed counter machine, and then weighed by using a sensitive balance. At harvesting time the total net plot area of 12 m^2 in which the 20 rows per plot were used to determine biomass and grain yield and converted into kilograms per hectare. Seeds per spike, the number of tillers, and spike length were also determined at harvesting.

2.5. Data Analysis

After collection of the agronomic data, analysis of variance was conducted for three years independently and combined analysis was used after the checking of homogeneity over the three years. Statistical Analysis System (SAS) statistical program (SAS, 2007) was used to analyze the collected data. Whenever the mean separation was calculated, ANOVA detected significant differences between treatments using the LSD at a 5% probability level.

3. Results and Discussion

3.1. Soil Physicochemical Properties before and after Lime Application.

The textural class of the study area was clay loam with the highest (37%) value of clay particle size and the lowest (30%) value of silt (Table 1). The study areas were characterized by fine texture class, and highly affected by the greater amount of clay contents which affected the soil physicochemical properties.

Table1. Physicochemical properties of the Soil in the study area before lime application.

Soil properties	Values
Clay	37
Silt	30
Sand	33
Textural class	Clay loam
pH(H_2O)	4.85
Bulk density (g/cm^3)	1.3
Organic carbon (%)	5.7
Total N (%)	0.43
Available P (ppm)	6.33
Exchangeable acidity (me/100g)	5.2

Getachew and Sommer (2000) showed that soils with pH values less than 5.5 are deficient in P and also Ca and Mg. In the study area, the soil pH (4.85) was very strongly acidic (Jones, 2003). The value of available P (6.33 ppm) was low according to Cottenie (1980). Thus, the status of soil fertility is low for barley production.

Soil analysis results after treatment application indicated that soil pH and available P value increased and exchangeable acidity decreased due to lime application compared to before planting, a sole application of inorganic fertilizer and control treatments (Table 2). It is in agreement with the findings of Ruganzu (2009), who stated that, the improvement in soil pH after application of limes in acidic soils. The application of lime improved H^+ and hydroxyl concentration in the soil solution to correct acidity; thus, the soil pH was improved (Castro and Crusciol, 2013). Due to Ca^{2+} ions contained in lime, the soil pH was improved because of Al^{3+} and H^+ ions replacement from soil adsorption sites (Kisinyo *et al*., 2012). Exchangeable acidity also decreased due to lime application when compared with before treatment application. This reduction is probably attributed to the improved Al replacement by the subsequent precipitation of Al as $Al(OH)_3$ and by Ca in the exchange place, as the soil becomes limed (Havlin *et al*., 1999). Available P values became maximum in treatments that received the lime applied at once (7.6 t ha^{-1}) during the first cropping season compared to sole inorganic fertilizer application and control. Still, this treatment was in the similar range of available P with the other limited treatments in different years. Application of inorganic fertilizer alone and control did not show any difference in terms of available P. Benvindo (2014) reported that lime applied alone significantly improved soil P availability. Achalu *et al*. (2012) also reported that soil pH increased due to the liming of acid soils and then released phosphate ions precipitated with Fe and Al ions which make P available for easy uptake of the plant. It is commonly known that reducing soil acidity leads to improved phosphorus availability (Gaume *et al*., 2001):

Table 2. Residual lime effects on soil physicochemical properties after harvesting

Treatments	Soil properties				
	pH (H_2O)	OC (%)	TN (%)	AvP (ppm)	EA ($cmol_+ kg^{-1}$)
Control	4.9	5.8	0.46	3.5	3.6
200 kg NPKSZnB + 94 kg ha^{-1} Urea	4.9	5.9	0.43	5.3	3.2
A full dose of lime once (7.6 t ha^{-1})	5.3	6.5	0.43	25.8	2.5
Two splits (1st and 2nd years)	5.8	6.7	0.44	18.6	3.1
Three splits (1st, 2nd and 3rd)	5.4	5.4	0.41	18.9	2.6
Two splits (1st and 3rd years)	5.5	6.1	0.48	24	2.8

TN = Total nitrogen, OM= Organic matter, AvP= Available phosphorus, OC=organic Carbon, ppm = parts per million

3.2. Lime Effects on Barley Growth Performance.

3.2.1. Number of tillers per plant and plant height.

The tiller number and plant height of barley become non-significantly ($P < 0.05$) influenced by lime application in the 2018 cropping season but in the third year during the 2020 cropping season, there were significant differences observed between lime-treated and untreated plots (Table 3 and 5). The highest plant height (104.3 cm) and tiller number (5.7) were obtained from two splits (1^{st} and 3^{rd} years) i.e., half at the initial year and the remaining half at the third year of lime application. In contrast, the minimum was obtained from the control (untreated plot) during the 2020 cropping season. The increment of plant height and tiller number of barley in acidic soils due to the application of liming material may be attributed to the increase in nutrient availability of Ca and P and a decrease in ion toxicity (Al, H, or Mn) (Achalu et al., 2012).

3.2.2. Number of seeds per spike and spike length.

Lime application significantly ($P<0.05$) enlarged the seed number and the spike length during the 2020 cropping season compared to untreated plots (Table 5). However, a non-significant difference was observed between split lime application and inorganic fertilizer alone. Combined analysis results showed that the maximum (7.0) spike length was recorded from two splits (1^{st} and 3^{rd} years) of application of lime, whereas the lowest was recorded from the control treatment (untreated plot) (Table 6). Geremew et al. (2020) reported that the combined application of lime and P fertilizer greatly contributed to the improvement of barley growth parameters like seed numbers and spike length compared to the control. Also, the authors showed that the number of seeds per spike and spike length can be a main yield-related parameter affected by soil acidity and become enhanced by the lime application.

3.3. Lime Effects on Yield and Yield-Related Parameters of Barley.

3.3.1. Aboveground biomass

The data indicated that the barley biomass was significantly ($P< 0.05$) influenced by the lime application when compared to untreated plots (no lime) each year. Over the years, biomass significantly enhanced with the split application of lime. The maximum biomass (8314.8 kg ha^{-1}) in the third year was recorded from two splits (1^{st} and 3^{rd} years) of lime application and the lowest (2777.8 kg ha^{-1}) from untreated plots (no lime). Biomass enhancement of 199.3% due to the two splits application (1^{st} and 3^{rd} years) over the control (Table 5). The enhancement of biomass with the split application of lime over the years on acidic soils is related to the decrease of acidic cations concentration and improvement in soil fertility. Achalu et al. (2012) described that lime application decreased the soil acidity adverse effect on the growth and development of plants because of the high concentration of Al^{3+} and H^{+} ions. Oluwatoyinbo et al. (2005) also indicated that the biological yield increment is related to the application of P fertilizers and lime through increasing soil acidity. This author also showed biological yield enhancement by the application of lime might have improved the availability of some plant nutrients like P and supply of Ca, neutralization of Al.

Table 3. Split application of lime on growth and yield of barley at Semen Ari during the 2018 cropping seasons.

Treatments	Tiller Number	Plant Height (cm)	Spike Length (cm)	Seed Number $Spike^{-1}$	1000 Seed Weight (g)	Biomass (kg ha^{-1})	Grain (kg ha^{-1})
Control	4.2	49.3	5.2b	30.2	26.9	2167b	207.6c
200 kg NPKSZnB + 94 kg ha^{-1} Urea	6.1	69.8	6.3ab	27.8	29.4	7000a	814.5a
Full dose of lime once (7.6t ha^{-1})	7.3	74.4	7.8a	32.7	29.1	8056a	944.5a
Two splits (1^{st} and 2^{nd} years)	6.1	62.3	6.2ab	23	25.3	6722a	656.7ab
Three splits (1^{st}, 2^{nd} and 3^{rd})	6.4	53.9	6.6ab	32.3	29.4	5833a	461.6bc
Two splits (1^{st} and 3^{rd} years)	4.2	53.1	7.1ab	30.1	25.8	6111a	692.8ab
Mean	5.7	60.5	6.5	29.3	27.6	5981.5	629.6
LSD (5%)	NS	NS	2.1	NS	NS	3210.6	289
CV	33.6	24.6	17.3	26.8	16.2	29.5	25.2

Mean values with different letters within a column are significantly different.
Note: 100kg NPKSZnB = 13.7 N- 27.4 P_2O_5- 14.4 K_2O + 5.1S + 0.54B.

Table 4. Split lime application on growth and yield of barley at Semen Ari during the 2019 cropping seasons

Treatments	Tiller Number	Plant Height (cm)	Spike Length (cm)	Seed Number Spike^{-1}	1000 Seed Weight (g)	Biomass (kg ha^{-1})	Grain (kg ha^{-1})
Control	0.8	71.0b	4.93	20.8	35.47b	1935b	651.3c
200kg NPKSZnB + 94 kg ha^{-1} Urea	0.8	74.2b	4.93	29.67	42.63a	3274b	1128.5abc
Full dose of lime once (7.6 t ha^{-1})	0.67	77.6ab	5.6	26.73	35.1b	3423ab	911.7bc
Two splits (1st and 2nd years)	1.07	85.93a	5.3	28.13	33.6b	6696a	1276.7abc
Three splits (1st, 2nd and 3rd)	1.07	76.6ab	5	31.87	33.6b	4464ab	1731.2a
Two splits (1st and 3rd years)	1.2	80.5ab	5.3	28.33	38.03ab	4315ab	1523ab
Mean	0.93	77.64	5.18	27.59	36.74	4017.86	1203.72
LSD (5%)	NS	10.47	NS	NS	6.97	3312.4	643.98
CV	21.6	7.41	9.86	23.39	10.43	25.31	19.41

Mean values with different letters within a column are significantly different.

Table 5. Split lime application on growth and yield of barley at Semen Ari during 2020 cropping seasons.

Treatments	Tiller Number	Plant Height (cm)	Spike Length (cm)	Seed Number Spike^{-1}	1000 Seed Weight (g)	Biomass (kg ha^{-1})	Grain (kg ha^{-1})
Control	1.9c	71.73b	5.9b	34.4b	32.6b	2777.8d	859.0d
200 kg NPKSZnB + 94 kg ha^{-1} Urea	4.3b	100.1a	8.9a	52.6a	34.4ab	3351.9cd	1249.3cd
Full dose of lime once (7.6 t ha^{-1})	4.6ab	102.3a	8.4a	47.0a	33.6ab	5046.3bc	1810.7bc
Two splits (1st and 2nd years)	3.8b	103.8a	8.1a	47.7a	33.3ab	6944.5ab	2520.8ab
Three splits (1st, 2nd and 3rd)	4.7ab	104.1a	8.5a	45.4a	34.3ab	7083.3a	2603.9ab
Two splits (1st and 3rd years)	5.7a	104.3a	8.7a	46.1a	36.35a	8314.8a	3061.5a
Mean	4.17	97.72	8.09	45.5	34.07	5586.43	2017.53
LSD (5%)	1.08	10.86	0.92	9.49	3.49	1940.8	811.53
CV	14.3	6.11	6.23	11.5	5.63	19.09	22.11

Mean values with different letters within a column are significantly different.

Table 6. Combined analysis of growth, yield and yield components of barley at Semen Ari district during 2018 to 2020 cropping season.

Treatments	Tiller Number	Plant Height (cm)	Spike Length (cm)	Seed Number Spike^{-1}	1000 Seed Weight (g)	Biomass (kg ha^{-1})	Grain (kg ha^{-1})
Control	2.3b	64.0c	5.35d	28.5b	31.7b	2293c	572.6d
200 kg NPKSZnB + 94 kg ha^{-1} Urea	3.7a	81.4ab	6.7bc	36.7a	35.5a	4541.9b	1064.1c
Full dose of lime once (7.6 t ha^{-1})	4.2a	84.8a	7.26a	35.5a	32.6ab	5508.3ab	1222.3bc
Two splits (1st and 2nd years)	3.7a	84.0ab	6.55c	32.9ab	30.7b	6787.6a	1484.7ab
Three splits (1st, 2nd and 3rd)	4.1a	78.2b	6.7bc	36.5a	33.1ab	5793.5ab	1598.9ab
Two splits (1st and 3rd years)	3.7a	79.3ab	7.0ab	34.9a	33.4ab	6247.1a	1759.1a
Mean	3.61	78.61	6.6	34.2	32.8	5195.24	1283.62
LSD (5%)	0.61	6.41	0.34	5.31	3.15	1484.2	407.76
CV	9.33	4.48	2.81	8.55	5.28	15.7	17.46

Mean values with different letters within a column are significantly different

3.3.2. Grain yield

Split lime application significantly (P<0.05) influenced grain yield in each year. The combined variance analysis also indicated significant (P<0.05) influenced grain yield (Table 6). During the initial year of the 2018 cropping season, (944.5 kg ha^{-1}) maximum grain yield was obtained (Table 3), but in the 2020 cropping season, (3061.5 kg ha^{-1}) maximum grain yield was obtained (Table 5). In the last year or 2020 cropping season of lime application, grain yield was enhanced by 256.4% as compared to the untreated plot. Overall, progressive improvements in grain yields were obtained over the years because of the split lime application. The maximum grain yield (3061.5 and 1759.1 kg ha^{-1}) in the third year cropping season and combined analysis were recorded from two split applications or 50% (1st and 3rd years), respectively. It was non-significant with the application of three splits or 33% in each year (1st, 2nd and 3rd years) and two splits or 50% (1st and 2nd years). However, the lowest grain yield was recorded from the control (untreated plot).

The progressive lime effect on barley yield was due to enhancing nutrient availability, improving the soil pH, and decreasing exchangeable acidity. Curtin and Syers (2001) reported that the grain yield of barley is enhanced as a result of liming acidic soils which decreases soil acidity and increases the availability of nutrients like P and Ca. Oluwatoyinbo *et al.* (2005) also reported that crop yield improvement is related to the application of P fertilizers and lime through increasing soil pH. In addition, this author also indicated that the grain yield enhancement by the application of lime can contribute to the supply of Ca, improving the availability of some plant nutrients, and neutralization of Al.

4. Conclusion and Recommendation

This study indicated that the split application of lime could reduce soil acidity and enhance the grain yield of barley as well as improve nutrient availability. The current study showed that the split lime application with recommended inorganic fertilizer improved barley production in the Semen Ari woreda of Southern Ethiopia. In the 2018 cropping season, the maximum grain yield of 944.5 kg ha^{-1} was obtained but in the third year (2020 cropping season), 3061.5 kg ha^{-1} maximum grain yield was recorded. In the third year (2020 cropping season) of lime application, grain yield was enhanced by 256.4% over the untreated plot. The maximum grain yields in the third year and combined analysis were recorded from the two split applications (1st and 3rd years) become statistically non-significant with the application of three split or 33% in each year (1st, 2nd, and 3rd years) and two splits or 50% (1st and 2nd years). This yield increment with the split application of lime over the years on acidic soils is related to the decreases of the acidic cation concentration and enhancement of nutrient availability. Application of two split or 50% (1st and 3rd years) with recommended inorganic fertilizers (69N and 46P_2O_5) was the optimum amendment in increasing barley grain yields in the study area. Farmers of the study area should adopt the split lime application with recommended rates of inorganic fertilizer rather than the sole application of inorganic fertilizers for barley production on strongly acidic soil. Further investigation should be done on plant nutrient uptake, nutrient use efficiency and optimization.

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