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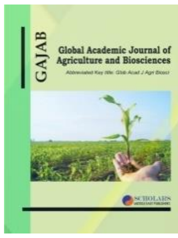

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Review Article

Response of Food Barley Acid Soil Properties to Lime and P Fertilizer Application in Loya District Sidama Ethiopia

Abreham Yacob[1*], Hana Mariyam Mekonnen[1]
[1]Department of Natural Resource Management, Wondo Genet Agricultural Research Centre, Shashemane, Ethiopia

***Corresponding Author**
Abreham Yacob
Department of Natural Resource Management, Wondo Genet Agricultural Research Centre, Shashemane, Ethiopia

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Abstract: Soil acidity is one of the chemical soil degradation problems that affect the productivity of the soil in Ethiopian highlands. The purpose of this research was to study the influence of lime and P fertilizer on the acid properties of soils under the Barley crop grown in the Loya southern region of Ethiopia. A field experiment was conducted at Loya Woreda for three consecutive seasons. The experiment comprised the following treatments; Five levels of Lime (0,58.5,117,175.5, and 234 kg/ha^{-1}) and Four Levels of phosphorous (0,23,46, and 69 kg/ha^{-1}) and was Laid out in a Randomized complete block design with three replications. The pooled mean analysis result showed that above ground, biomass was significantly ($p>0.05$) influenced by the application of phosphorus fertilizer, lime, and their interaction. The maximum and minimum above-ground biomass is 16840 kg/ha and 9920 kg/ha. They obtained at 46 kg P ha-1 and control treatments, respectively. Amongst the liming treatments, liming at 117kg/ ha gave significantly ($P < 0.05$) the highest above-ground biomass of barley. Similarly, the grain yield of barley was significantly influenced by applying different phosphorus fertilizers; the highest gain yield was obtained at 46 kg P ha^{-1}. However, grain yield was not significantly affected by applications of different levels of lime but numerically highest grain yield (2320 kg/ha) was obtained at 117kg/ha of lime. In all harvesting seasons, and pooled mean of TSWT did not show significant variation among different levels of phosphorus and lime. Hence, for sustainable and higher productivity, barley production in Loya southern Ethiopia should be 117 kg ha^{-1}lime and46 kg P ha^{-1}. However, the effect of lime application on soil reaction and exchangeable acidity was not properly discussed in this particular study due to a lack of soil laboratory results.

Keywords: Grain Yield, Grain Yield Response Index, Interaction Effect, Soil Acidity.

INTRODUCTION

Soil acidity is a significant challenge to agricultural productivity worldwide, affecting over 30% of total agricultural land and 50% of potential farmland globally. This issue is particularly severe in Sub-Saharan Africa, including Ethiopia, where up to 43% of arable land in the highlands is impacted due to high rainfall and steep terrain. Acidic soils result in deficiencies of essential nutrients like calcium, potassium, and magnesium, limiting nutrient absorption, root growth, and crop yields. Yield losses

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exceeding 50% are attributed to low soil pH across various crops.

The primary causes of soil infertility include aluminum, manganese, and iron toxicity, coupled with deficiencies in calcium, magnesium, potassium, and phosphorus. These conditions reduce soil fertility and hinder crop cultivation. Applying lime is a proven solution to mitigate soil acidity by increasing pH, reducing aluminum toxicity, and improving nutrient availability. Lime also enhances soil microbial activity, fostering a healthier soil environment. Effective management of soil acidity, particularly through lime application, is essential for sustainable farming, improved crop development, and increased agricultural output globally.

Barley (*Hordeum vulgare* L.) is a globally significant cereal crop and the dominant cereal grown in the highlands of Ethiopia, covering 1.02 million hectares with an average productivity of 1.87 tons per hectare (CSA, 2014). In Ethiopia, it ranks as the fifth most important cereal crop after teff (*Eragrostis tef*), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), and wheat (*Triticum aestivum* L.). Barley is the staple food for Ethiopian highlanders, who use indigenous technologies to prepare traditional foods like *kita*, *kolo*, *beso*, *injera*, and the local beverage *tela*. It is also a key raw material for various industries.

However, barley production in Ethiopia faces significant challenges. Dependence on traditional varieties and farming practices, cultivation in marginal areas with poor soil fertility, rampant soil acidity in the highlands, and the prevalence of diseases and pests all contribute to its low yield.

As a result, current barley production in Ethiopia is insufficient to meet the demands of the rapidly growing population.

Soil acidity remains one of the major bottlenecks to barley production in Ethiopia's highlands, a problem that has not been adequately addressed. Consequently, small-scale farmers in these areas have nearly abandoned barley production due to severe soil acidity.

To mitigate the effects of soil acidity and improve soil fertility, farmers practice a barley–bare fallow–oats rotation system (Hailu & Getachew, 2011). However, this system is unsustainable in the long term, as it degrades soil resources due to severe soil erosion during the bare fallow phase.

Additionally, farmers are reluctant to apply phosphorus (P) fertilizer due to the low response to P application caused by phosphorus fixation.

Phosphorus reacts with iron and aluminum oxides/hydroxides under acidic conditions, forming insoluble phosphates and reducing P availability to plants (Kamprath, 1984). As a result, phosphorus deficiency often occurs simultaneously with aluminum toxicity in these soils.

Efforts to ameliorate the adverse effects of soil acidity must therefore include measures to increase available P in soils. The addition of lime to acid soils has been a widely adopted strategy for improving crop production for many years, though its use remains limited in Ethiopia. Combining lime with P fertilizer is an important approach for improving crop growth in acid soils.

However, there is a lack of information on the interactive effects of lime and P fertilizer on crop performance in Southern Ethiopia. The objective of this study was to investigate the interactive effects of lime and P fertilizer on barley grain yield and soil chemical properties under acidic soil conditions in southern Ethiopia.

MATERIAL AND METHODS

Description of Experimental Area

This study was carried out at Loy in Sidama zone, which is found in the Southern Nations Nationalities and Peoples Regional State. It is located 356 km south of Addis Ababa. The study area is located on latitude of at 6°-9, N and 35°3'E. With an elevation of 3050m.a.s.l.

Experimental Layout and Treatment Application

This activity was based on a crop rotation system involving barley cereal and faba bean legume crops, conducted in two sets. In each season, barley and faba bean were sown simultaneously in different sets within the same block. The experiment followed a randomized complete block design (RCBD) arranged factorially, with five levels of lime application (0.0x, 0.5x, 1.0x, 1.5x, and 2.0x, based on exchangeable Al^{3+} and H^{+} content of the soil) and four levels of phosphorus (0, 23, 46, and 69 kg/ha). This resulted in twenty treatments, each replicated three times.

A high-yielding food barley variety, *Hb-1307*, was used as the test crop at a seed rate of 125 kg/ha. The plot size was 4.5 × 5.1 meters (22.95 m^2), and all plots were hand-weeded at 30 and 60 days after sowing. Faba bean (*Vicia faba L.*) served as the preceding crop for the food barley (*Hordeum vulgare L.*). The lime requirement for each level was calculated based on the mass of soil in a 15 cm hectare-furrow-slice, soil density, and exchangeable Al^{3+} and H^{+} content. The calculation followed an equation that assumes one mole of $CaCO_3$ neutralizes one mole of exchangeable acidity. In the first year, the total lime dosage was applied in a single application, spread evenly by hand, and incorporated into the soil at least one month before planting. Nitrogen (N) and phosphorus (P) were applied at recommended rates, with urea used as the N source and triple superphosphate (TSP) as the P source. Urea was applied in two split doses, while the entire phosphorus dosage was band-applied at sowing. The plots were maintained permanently to observe the residual effects of lime throughout the experiment. Data on growth, yield, and yield components were collected. At crop maturity, the entire plot area (14 m^2) was hand-harvested at ground level from each plot to determine grain yield and biomass yield. Soil samples were randomly collected prior to the experiment and after harvesting to analyze soil pH and exchangeable acidity. Soil pH was measured using a pH meter in a 1:2.5 soil-to-water suspension, while exchangeable acidity was extracted with 1M KCl.

Plant Data Collection

The above-ground parts of the barley plants were harvested at heading. Cutting was done at the soil surface and the materials were dried in an oven at 65°C for 48 h, weighed, and ground to pass through a 1 mm sieve, and saved for P content determination.

Partial Budget Analysis /Economic Analysis

Economic analysis was conducted using the CIMMYT partial budget methodology (CIMMYT, 1988). The net benefit (NB) was calculated as the difference between the gross field benefit (GB), expressed in Ethiopian Birr (ETB ha^{-1}), and the total variable costs (TVC), also in ETB ha^{-1}. The average market price of each type of inorganic fertilizer was determined in Birr per 100 kg, while labor costs for fertilizer application were estimated based on the number of person-days required. The cost per person-day of labor was also expressed in Birr.

Using the CIMMYT methodology, TVC, GB, and NB were calculated for each treatment. Treatments were then ranked in ascending order of TVC, and a dominance analysis was conducted to identify and exclude dominated treatments. Finally, the marginal rate of return (MRR) analysis was performed on the remaining treatments to determine their economic feasibility.

Statistical Data Analysis

The collected data was entered into Microsoft excel and subjected to analysis of variance (ANOVA) using SAS software version 9.4. Since the ratio of the largest standard error (SE) to the smallest SE was less than 3, indicating homogeneity across experimental locations, combined data analysis for various parameters was performed across locations (Gomez, 1984).

RESULTS AND DISCUSSION

Selected chemical properties of the soil prior to the application of the treatments are presented in (Table 1).

Table 1: Effects of Phosphorus and Lime affected by PH, EA, Avail P and All O^3 as in 2015/16 to 2017/2018 year at Loya woreda cropping season

pH (H_2O)	Particle size			Textural class	Avia.p	OC	Exch. Acidity (Al^{3+}+H^+)
	clay	sand	Silt				
4.78	43	30	25	Cl	7.55	0.21	1.06

Significantly different p<0.05

Physicochemical Properties of the Experimental Area Soil

Selected Soil Properties before Sowing

Soil analysis results are indicated in (Table 1). According to rating by Tekalign *et al.,* (1991) the soils of the study areas were strongly acidic at Loya districts; hence being unsuitable for plant growth. The soil OC was very low as rated by Tekalign *et al.,* (1991), while very low in avail. P as rated by Jones (2003). The textural classes of soils were clayey at all site. Finally, the analysis result confirms as OC and avail. P contents of soils of all the experimental sites were low and the soil reaction was acidic (Table 1), which can depress plant growth and affects crop productivity.

Selected Soil Chemical Properties after Harvesting

The results of soil analysis after crop harvest are presented in (Tables 2). The interaction effect of lime and phosphorus (P) fertilizer was significant (P<0.05) on selected soil chemical properties, such as exchangeable aluminum (Ex*Al), particularly in the soils of the Loya district following the harvest of food barley. Most of the studied soil parameters showed significant variation in response to lime application. The independent effect of lime was notably significant on soil available phosphorus in the Loya district. Similarly, lime application significantly influenced soil pH and exchangeable aluminum across all sites after harvest. Furthermore, the response of soil available phosphorus to applied P fertilizer was highly significant (P<0.05), as indicated (Table 4).

Effects of Lime and Phosphorus Fertilizer on Soil Properties

The application of phosphorus (P) fertilizer at a rate of 33 kg/ha resulted in the highest significant ($P<0.05$) increase in soil available phosphorus after harvesting in the Loya district (Table 4). Soil reaction (pH) increased with higher lime application, while exchangeable acidity and aluminum decreased significantly. This demonstrates that the applied lime effectively neutralized soil acidity, raising the pH and reducing exchangeable acidity and aluminum levels. Getachew *et al*., (2017) highlighted that lime amendment mitigates soil acidity by detoxifying aluminum (Al) and manganese (Mn) activity. Detoxification of Al occurs as soil pH increases, reducing Al solubility and minimizing its toxic effects on plants. Similarly, Nduwumuremyi *et al*., (2014) noted that plant growth in acid soils improves not only through the addition of basic cations (Ca, Mg) but also due to increased pH, which alleviates Al toxicity. Peter (2017) also reported that lime application significantly reduced exchangeable acidity compared to untreated plots.

In this study the pH of the soils improved after application of lime from initial 4.78, to 5.95 at Loya district. Application of lime highly decreased Ex, acidity as the level of applied lime rates increased. The Ex*acidity decreased from initial 1.06, to 0.20 Cmol $_{(+)}$ kg^{-1} soil at Loya district, respectively; This happened This has contributed to better improvement in soil properties. Similar result was reported from the study on Kenyan soil by Mohammed *et al.,* (2016).

Plant Height

The mean square values for the studied parameters of food barley are presented in Table 5. The interaction effect of lime and phosphorus (P) fertilizer was significant ($P<0.05$) for certain parameters. Additionally, the main effect of lime significantly influenced the plant height of food barley ($P<0.05$) in the Loya district. Similarly, the independent application of P fertilizer significantly affected the plant height of food barley in the same district (Table 2).

Table 2: Effects of Phosphorus and Lime affected by PH, EA, and Avail P as in 2015/16 to 2017/2018 year at Loya woreda cropping season

TRT	pH 1:2.5	Avail. P	Ex. acidity cmol/kg	Ex*Al cmol/kg
1	**4.72^{cde}**	5.74^{b}	0.97^{abcd}	0.66^{bcdef}
2	5.03^{c}	4.59^{b}	0.33^{bcd}	0.13f
3	4.73^{cde}	5.44^{b}	1.56^{a}	0.45^{cdef}
4	4.53e	4.47^{b}	1.02^{abcd}	0.70^{bcde}
5	4.70^{cde}	4.71^{b}	1.28^{ab}	0.89^{bcd}
6	4.81^{cde}	11.86^{a}	0.98^{abcd}	0.86^{bcd}
7	4.74^{cde}	5.26^{b}	1.16^{abc}	0.71^{de}
8	4.97^{cd}	3.72^{b}	0.20^{cd}	0.31^{def}
9	4.73^{cde}	6.19^{b}	1.18^{abc}	0.70^{bcde}
10	4.97^{cd}	5.49^{b}	0.30^{bcd}	0.39^{cdef}
11	5.66^{ab}	10.98^{a}	0.61^{abcd}	0.29^{def}
12	4.85^{cde}	4.97^{b}	0.95^{abcd}	1.03^{ab}
13	4.84^{cde}	4.08^{b}	0.48^{bcd}	0.48^{cdef}
14	4.90^{cd}	4.59^{b}	0.49^{bcd}	0.27^{def}
15	4,82^{cde}	4.71^{b}	0.67^{abcd}	0.55^{bcdef}
16	4.64^{de}	5.43^{b}	0.98^{abcd}	0.72^{bcde}
17	5.91^{a}	11.75^{a}	0.20^{cd}	1.32^{a}
18	**5.95^{a}**	**12.36^{a}**	**0.09^{d}**	0.29^{def}
19	6.00^{a}	12.06^{a}	0.34^{bcd}	0.19^{ef}
20	5.54^{a}	11.14^{a}	0.73^{abcd}	0.61^{bcdef}
LSD@ (0.05)	0.36	3.92	0.99	0.54
CV (%)	2.02	8.7	6.53	5.45

Significantly different $p<0.05$. (pH, Avai.P, Exchangeable acidity, Exchangeable aluminium.

Effects of Lime, and Phosphorous on Plant Height and Spike Length

The analysis of variance revealed that the application of different levels of phosphorus (P) fertilizer brought significant variation in plant height. The highest pooled mean plant height was observed at 69 kg P/ha, although it was statistically comparable to the control treatment (Table 1). Similarly, plant height was significantly influenced by lime application. The highest pooled mean plant height was recorded at 117 kg lime/ha, while the lowest was observed in the control treatment.

However, the application of different levels of P, lime, and their interaction did not result in any significant variation in spike length. The pooled mean analysis consistently showed that plant height improved with the application of 69 kg P/ha and 117 kg lime/ha. This indicates the importance of these levels in enhancing barley growth.

These findings suggest that for sustainable barley production in the highlands of Ethiopia, the combined application of lime and P fertilizer is essential for managing acidic soil conditions. The use of 69 kg P/ha and moderate lime levels, such as 117 kg lime/ha, is recommended for improving plant height and addressing soil acidity. This integrated nutrient management approach not only enhances crop productivity but also provides economic benefits. In conclusion, the application of phosphorus fertilizer and lime plays a critical role in improving plant height and supporting sustainable barley production in acidic soils.

Table 3: Plant Height and Spike Length of Barley as Affected by Phosphorus Fertilizer, Lime, and Their Interaction

TRT	PH (cm)				SL (cm)			
P. LEVEL (kg/ha)	**2015**	**2016**	**2017**	**Pooled mean**	**2015**	**2016**	**2017**	**Pooled mean**
Control	107.2	104.7ab	96.77a	101.96a	7.2	5.52	4.21a	5.67
23	96.6b	102.6ab	82.13b	94.26b	7.36	5.3	3.45b	5.37
46	95.11	101.6b	83.33b	93.89b	7.5	5.63	3.49b	5.56
69	105.05	106.69	93.3a	102.93a	7.38	5.52	3.82ab	5.57
LSD@0.05	4.1	4.2	7.7	3.33	Ns	ns	0.62	ns
LIME Level kg/ha								
Control	100.01	104.9	84.18b	96.07b	7.5	5.49	3.81	5.61
58.5	99.7	104.7	85.06b	96.63b	7.3	5.63	3.6	5.52
117	103.7	103.3	97.20a	102.17a	7.3	5.31	3.83	5.48
175.5	100.5	102.7	90.13ab	98.77ab	7.3	5.41	3.74	5.49
234	99.9	104	87.91b	97.66b	7.4	5.61	3.76	5.62
LSD@0.05	4.5	4.7	8.69	3.72	0.7	0.39	0.7	0.35
P*L	***	ns	***	***	Ns	ns	ns	ns
CV	5.5	5.5	11.85	8.12	11.6	8.7	22.73	13.54

Significantly different p<0.05. (PH) plant height, (SL) spike length.

Effects of Phosphorus and Lime on Above-Ground Biomass, Grain Yield, and 1000-Seed Weight in Acidic Soils

The pooled mean analysis indicated that above-ground biomass was significantly ($P < 0.01$) influenced by the application of phosphorus (P) fertilizer, lime, and their interaction. This suggests that the response of above-ground biomass to varying levels of P fertilizer was modified by the levels of lime applied. The maximum above-ground biomass (16840kg/ha) was recorded at 46 kg/ha, while the minimum (9920 kg/ha) was observed in the control treatment without P application. Among the lime treatments, applying 117 kg/ha lime resulted in the highest above-ground biomass, significantly outperforming other lime levels ($P < 0.05$).

Similarly, barley grain yield was significantly influenced by the application of different P fertilizer levels, with the highest grain yield obtained at 46 kg P/ha. However, grain yield was not significantly affected by varying lime levels, although the numerically highest yield (2320 kg/ha) was recorded at 117 kg/ha lime application.

In contrast, the 1000-seed weight (TSW) did not show significant variation across different levels of P fertilizer or lime in any harvesting season or the pooled mean analysis.

These findings highlight that for sustainable barley production on acidic soils, such as those found in the highlands of Ethiopia, combined applications of lime and P fertilizer are essential. Lime improves soil pH, enhancing nutrient availability, while P fertilizer addresses phosphorus deficiencies, both of which are critical for improving crop productivity in acidic soils.

Table 4: Means for above-ground biomass, grain yield, and 1000 seed weight of barley as affected by phosphorus fertilizer, lime, and their interaction at Loya during the 2014/2015 to 2017/2018 cropping seasons

TRT	AGB (kg/ha)				GY (kg/ha)					TSW (g)		
P. level (kg/ha)	2015	2016	2017	Pooled mean	2015	2016	2017	Pooled mean	2015	2016	2017	Pooled mean
0	2.97	4.70	6.74^{b}	9920	0.59	0.98	0.95	1890	10.91	37.12	39.84	61.31
23	2.77	8.12	8.12^{ab}	12930	0.51	1.08	1.05	1940	9.70	39.97	36.09	61.70
46	3.98	9.58	9.85^{a}	16840	0.53	1.04	1.62	2110	9.60	40.45	34.89	61.68
69	2.82	9.18	5.39^{ab}	1380	0.52	1.24	1.64	2310	9.30	40.94	38.83	63.18

TRT	AGB (kg/ha)				GY (kg/ha)					TSW (g)		
LSD@0.05	0.48	1.41	1.37	1.06	0.09	0.33	0.33	0.52	1.1	5.72	18.83	8.55
LIME Level kg/ha												
0	2.90	7.68	7.26	13000	0.59	0.95	1.19	1940	10.30	42.42	30.13	62.76
58.5	2.50	8.20	8.47	13520	0.53	1.07	1.67	2160	9.80	39.17	31.66	59.52
117	2.70	9.11	9.91	15110	0.52	1.18	1.87	2320	10.02	37.61	39.91	60.93
175.5	2.90	8.91	9.67	15030	0.57	1.12	1.72	2260	10.30	38.43	34.58	60.26
234	2.70	7.98	5.06	12370	0.51	1.02	1.64	2080	9.80	38.47	33.81	59.54
LSD@0.05	0.54	1.58	1.53	**1.21**	0.1	0.36	0.37	**0.27**	1.2	6.39	21.06	**9.55**
P*L	**	Ns	**	***	ns	Ns	**	**	ns	ns	ns	**ns**
CV	23.59	22.8	35.23	**27.20**	22.8	21.46	26.3	**23.52**	15.08	19.57	29.89	**21.51**

Significantly different ($p<0.05$). (AGB) above ground bio mass, (GY) Grain yield, (TSWT) Thousand seed weight.

CONCLUSION AND RECOMMENDATION

This study revealed that the acidic soils of Loya, southern Ethiopia, are highly responsive to lime and phosphorus (P) fertilizer treatments, which significantly improved soil chemical properties, above-ground biomass, and barley grain yield.

Key Findings:

Soil Properties:

Lime application effectively neutralized soil acidity, increasing the pH from 4.78 to 5.95 and reducing exchangeable acidity from 1.06 to 0.20 cmol/kg. The application of 46 kg P/ha greatly enhanced soil available phosphorus, contributing to better crop performance.

Barley Growth and Yield:

The combined application of 117 kg lime/ha and 46 kg P/ha resulted in the highest above-ground biomass (16.84 t/ha) and substantial increases in grain yield. Plant height was significantly influenced by lime and phosphorus, with the highest pooled mean plant height observed at 117 kg lime/ha and 69 kg P/ha.

Integrated Nutrient Management:

The interaction between lime and P fertilizer significantly affected soil properties, above-ground biomass, and barley grain yield, emphasizing the importance of integrated nutrient management for acidic soils. These findings underscore the critical role of lime and phosphorus in improving soil fertility and crop productivity in acidic soils.

Optimal Nutrient Management:

For sustained barley production in Ethiopia's highlands, a combination of 117 kg lime/ha and 46 kg P/ha is recommended. This approach addresses soil acidity and phosphate deficiencies, leading to improved crop productivity.

Soil Testing and Monitoring:

Regular soil testing is essential to monitor changes in soil pH, exchangeable acidity, and nutrient availability. This allows for adjustments to lime and fertilizer application rates as needed.

Future Research and Recommendations:

Future studies should focus on assessing the long-term effects of lime and phosphorus treatments on soil properties, such as soil response, exchangeable acidity, and nutrient dynamics, to refine nutrient management strategies. Findings disseminated through farmer training programs and agricultural extension agencies can stimulate the use of lime and phosphorus fertilizers. This could increase barley yield in Ethiopia's acidic soils while also addressing soil acidity and nutrient deficiencies. Lime and phosphorus fertilizers are crucial to boosting barley results while ensuring sustainable soil management in acidic soils. These findings can help farmers and policymakers improve nutrient management methods, leading to increased agricultural output and economic advantages for the region. This integrated method promotes sustainable agriculture and better lives for farmers in Ethiopia's highlands.

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