academicJournals

Vol. 12(40), pp. 3005-3012, 5 October, 2017
DOI: 10.5897/AJAR2017.12562
Article Number: 945989266219
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Effect of lime and phosphorus fertilizer on acid soil properties and barley grain yield at Bedi in Western Ethiopia

**Getachew Alemu, Temesgen Desalegn, Tolessa Debele*, Ayalew Adela, Geremew Taye and Chelot Yirga**

Ethiopian Institute of Agricultural Research, P. O. Box 2003, Addis Ababa, Ethiopia.

Received 29 June, 2017; Accepted 26 July, 2017

**Soil acidity associated with soil fertility problems are the main constraints hindering barley production in most highlands of Ethiopia. Field experiment was conducted to evaluate effects of lime and phosphorus (P) fertilizer application to acid soils on grain yield of barley and soil chemical properties during 2009 to 2013 cropping seasons at Bedi in Western Ethiopia. The experiment was laid out in randomized complete block design with three replications. Five levels of lime (0, 0.55, 1.1, 1.65 and 2.2 t/ha) and four levels of P (0, 10, 20, and 30 kg/ha) were combined in a complete factorial arrangement. Lime requirement of the soil was calculated based on its exchangeable acidity. The combined analysis over years showed significant improvement of barley grain yield and soil chemical properties due to the main and interaction effects of lime and phosphorus. Grain yield was progressively increased with incremental levels of lime and Phosphorus application. The highest yield was obtained from 2.2 t/ha lime application coupled with 30 kg/ha phosphorus fertilizer, but on par with 1.65 t/ha lime and 20 kg/ha phosphorus application. Grain yield is increased by 274.0% with 1.65 t/ha lime and 20 kg/ha Phosphorus application in the initial year compared with control; however, this yield increment declined over years and reached 99.5% after five years. This yield reduction after five years of lime application may indicate re-acidification of the soil which warrants re-liming. In this study, lime application was the major source of variation for soil chemical properties. Soil pH was sharply increased by liming with the highest value (5.9) and thereafter slightly declined to 5.3 over five years. Exchangeable acidity decreased significantly with increase in lime application to as low as 0.1 cmol/kg, while available P and exchangeable $Ca^{2+}$ were noticeably improved. Hence, lime application at the rate of 1.65 t/ha coupled with 20 kg/ha Phosphorus fertilizer could sustainably enhance barley production on acid soils of Bedi and similar areas with likely re-liming of the soils, every five years.**

**Key words:** Acid soils, barely, lime application, phosphorus fertilizer, soil properties.

## INTRODUCTION

Soil acidity is a major environmental and economic concern in many areas of Ethiopia which causes significant losses in crop production. Soil acidity is a complex of several factors involving plant nutrient deficiencies and toxicities, low activities of beneficial microorganisms, and reduced plant root growth which limits absorption of nutrients and water (Fageria and Baligar, 2003). Poor crop production on acidic soil has long been associated with aluminum ($Al^{3+}$) toxicity, reduced nodulation or mycorrhizal infections and low phosphorus (P) availability (Kochian et al., 2004; Wang et al., 2006).

Soil acidity and $Al^{3+}$ toxicity in surface soil can be ameliorated through liming (Fegeria and Baligar, 2008; Rebecca 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).

In Ethiopia, large areas of highlands with altitude of >1500 m located in almost all regional states of the country are affected by soil acidity. According to Ethiosis (2014) about 43% of the Ethiopian arable land is affected by soil acidity. Also, Mesfin (2007) reports that moderately acidic soils with pH less than 5.5 considerably influence crop growth and require intervention. The main factors giving rise to increased soil acidity in Ethiopia include climatic factors such as high amount of precipitation (that exceeds evapo-transpiration which leaches appreciable amounts of exchangeable bases from the surface soil), temperature, severe soil erosion, morphological and anthropological factors. The largest areas of the Western Oromia highlands are dominated by Nitisols with high acidity (Mesfin, 1998; Temesgen et al., 2011).

Barley (*Hordeum vulgare* L.) is the dominant cereal crop grown in the high lands of Ethiopia where soil acidity is rampant. Barley production covers a total area of 1.02 million ha with a national average productivity of 1.87 t/ha (CSA, 2014). Soil acidity is considered to be one of the major bottlenecks to barley production in the highlands of Ethiopia. The problem still persists and has not been addressed sufficiently. Consequently, small-scale farmers in the highlands of the country have almost given up barley production to the severe soil acidity. Farmers practice barley– bare fallow–oats rotation system reduces the negative effects of soil acidity and improve soil fertility (Hailu and Getachew, 2011). However, this rotation system is not sustainable and in the long run will degrade the soil resource due to severe soil erosion on the bare fallow. Farmers are not encouraged to apply P fertilizer due to low response to P application as a result of P fixation.

Phosphorus reacts with Fe and Al oxides/hydroxides under acidic conditions to form insoluble phosphates, hence reducing P availability to plants (Kamprath, 1984). Phosphorus deficiency often, therefore, occurs simultaneously with $Al^{3+}$ toxicity in these soils. Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to increase available P in soils. Addition of lime to acid soils has long been widely adopted as, the amelioration strategy for many years to improve crop production which is rarely used in Ethiopia.

Appropriate combination of lime and P fertilizer is therefore an important strategy for improving crop growth in acid soils. There is however, scarcity of information on interactive effects of lime and P fertilizer application on crop performance in western Ethiopia. The objective of this study was therefore, to investigate the interactive effects of lime and P fertilizer on barely grain yield and soil chemical properties under acid soil condition in Western Ethiopia.

## MATERIALS AND METHODS

### Study site

The study was conducted for five consecutive years during 2009 to 2013 main cropping seasons at Bedi in western Ethiopia. Bedi is located on longitude 9°05' N, latitude 38°36' E and 2565 m altitude in the central highlands of Ethiopia (Figure 1). The site is typically characterized by plains with cool subtropical climate.

The area receives an average annual rainfall of 1100 mm with bimodal distribution of January to March (small rain) and June to September (major season). The soils are classified as Nitisols with deep, red, and well-drained tropical soils. The following criteria were set for selecting suitable site: the soils should be fairly well representative for barley production in the area; the soil should have pH values of lower than 5.5, and the soils should have no previous liming history. Some of the physical and chemical characteristics of the experimental site are summarized in Table 1.

### Experimental design and procedures

The experiment was laid out in a randomized complete block design with three replications. Five levels of lime (0, 0.55, 1.10, 1.65, 2.20 t/ha) and four levels of P (0, 10, 20, and 30 kg/ha) were combined in a complete factorial arrangement. Lime requirement of the soil was calculated based on its exchangeable acidity ($Al^{3+}$ plus $H^{1+}$) adapted from (Kamprath, 1984).

The aforementioned five levels of lime correspond to 0, 50, 100, 150 and 200% of the lime are required to neutralize the exchangeable acidity of the soils. Good quality commercial grade agricultural lime ($CaCO_3$) with 98% neutralizing value and <250 µm in diameter was used. Lime was applied uniformly in broadcast by hand to every plot a month before sowing and soil incorporated by oxen plowing only in the initial year. The experimental plots were kept permanent to observe the residual effects of lime application over years.

Triple super phosphate (TSP) and urea were used as inorganic fertilizer sources and applied every year. The entire dose of TSP was applied at planting, while the recommended N rate (46 kg/ha) was applied in split, *viz*: half at sowing and the remaining half side dressed at tillering stage of barley. Gross and net plot sizes were 4

---

*Corresponding author. E-mail: tolessadebele@yahoo.com. Tel: +251 912021610.

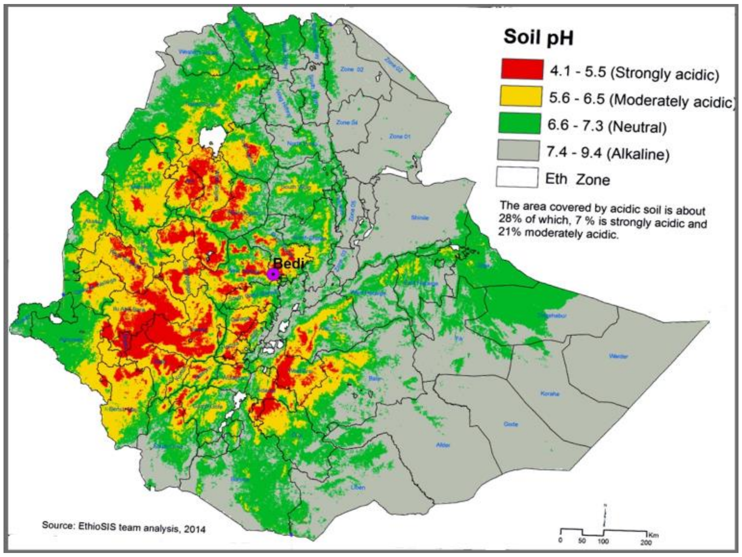

**Figure 1.** Bedi site and acid soil map of Ethiopia.

**Table 1.** Some physical and chemical soil characteristics of the Nitisols at Bedi site before commencement of the experiment.

| Parameter | Value |
|---|---|
| Particle size distribution (%) | - |
| Sand | 21.25 |
| Silt | 38.75 |
| Clay | 40.00 |
| Bulk density (g $cm^{-3}$) | 1.15 |
| pH ($H_2O$ 1:2.5) | 4.80 |
| Organic carbon (%) | 2.46 |
| Total nitrogen (%) | 0.22 |
| Available phosphorus (mg $kg^{-1}$) | 6.40 |
| CEC (cmol/kg) | 7.36 |
| Exchangeable Ca (cmol/kg) | 4.17 |
| Exchangeable Mg (cmol/kg) | 1.43 |
| Exchangeable K (cmol/kg) | 1.09 |
| Exchangeable Na (cmol/kg) | 0.15 |
| Exchangeable acidity (cmol/kg) | 1.32 |

m × 5 m and 3 m × 4 m, respectively. Food barley variety BH-1307 was used as a test crop.

### Soil sampling and analyses

Composite surface (0 to 20 cm) soil samples were collected from each plot and analyzed for soil physical and chemical properties during the initial year and subsequent alternative years. A 5 cm diameter auger was used to sample five randomly selected spots per plot. These sub-samples were thoroughly mixed, homogenized, air dried under shade, ground and passed through a 2 mm sieve.

The samples were analyzed for soil texture, pH, available P, total N, organic carbon, exchangeable acidity $Al^{+3}$, exchangeable cations ($Ca^{2+}$, $Mg^{2+}$, $K^{+}$, $Na^{+}$) and cation exchange capacity (CEC) using the procedures outlined in Page et al. (1982).

### Statistical analysis

Analysis of variance was conducted for each year separately and combined analysis over the five years. Analyses of variance were performed using the Statistical Analysis System (SAS) statistical program (SAS V8.2, SAS Institute Inc., Cary, NC, USA).

Whenever the ANOVA detected significant differences between treatments, mean separation was conducted using least significant difference (LSD). Pearson correlation coefficients were also used to assess the significance of the relationships between yield and some soil properties.

## RESULTS AND DISCUSSION

### Grain yield

The factorial analysis of variance indicated that lime and P fertilizer application significantly ($P<0.05$) affected barley grain yield in each year (Table 2). However, interaction effect of lime and P fertilizer application on grain yield of barley was found significant only during the initial three consecutive years. The combined analysis of variance over years showed highly significant ($P<0.05$) lime, P, lime × P interaction effects on barley grain yield (Table 2).

In general, progressive increases in grain yields were recorded with incremental levels of lime and P fertilizer application. Grain yield response was found more pronounced with the first than the second increment of lime and P application. The highest barley grain yields in each year and combined analysis were obtained from the

**Table 2.** Effects of lime and phosphorus fertilizer application on grain yield of barley (kg/ha) at Bedi during 2009 to 2013 cropping seasons.

| Lime levels (t/ha) | 2009 | | | | | 2010 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P levels (kg/ha) | | | | | P levels ( kg/ha) | | | | |
| | 0 | 10 | 20 | 30 | Mean | 0 | 10 | 20 | 30 | Mean |
| 0 | 1256 | 2059 | 2397 | 3060 | 2193 | 1446 | 2181 | 2556 | 2701 | 2221 |
| 0.55 | 2132 | 2501 | 3447 | 3833 | 2978 | 2263 | 2592 | 3166 | 3881 | 2975 |
| 1.10 | 2398 | 3184 | 4362 | 4675 | 3655 | 2375 | 3271 | 4276 | 4428 | 3588 |
| 1.65 | 2536 | 3995 | 4697 | 5117 | 4086 | 2751 | 3682 | 4687 | 4873 | 3998 |
| 2.20 | 2498 | 3769 | 4846 | 4976 | 4022 | 2895 | 3958 | 4973 | 5365 | 4298 |
| Mean | 2164 | 3102 | 3950 | 4332 | | 2346 | 3137 | 3931 | 4250 | - |
| | LSD (0.05) L= 176.72, P =158.06, L x P = 358.2 | | | | | LSD(0.05) L= 244.2, P =218.4, L x P=751.0 | | | | |
| | CV (%) = 6.32 | | | | | CV (%) = 8.66 | | | | |
| | 2011 | | | | | 2012 | | | | |
| 0 | 1716 | 2139 | 2443 | 2692 | 2248D | 1352 | 1863 | 2489 | 2627 | 2083 |
| 0.55 | 2270 | 2638 | 3189 | 3540 | 2909 | 2413 | 2571 | 2921 | 3251 | 2789 |
| 1.10 | 2410 | 3657 | 3951 | 4302 | 3580 | 2599 | 2836 | 3307 | 3634 | 3094 |
| 1.65 | 2648 | 4300 | 4718 | 4858 | 4131 | 2766 | 3143 | 3569 | 3716 | 3298 |
| 2.20 | 2832 | 4490 | 4571 | 4885 | 4170 | 2814 | 3222 | 3639 | 3721 | 3349 |
| Mean | 2375 | 3445 | 3774 | 4035 | | 2389 | 2727 | 3185 | 3390 | |
| | LSD (0.05) L= 225.7, P =201.9, L x P = 430.2 | | | | | LSD(0.05) L= 217.15, P =194.22, L x P= NS | | | | |
| | CV ( %) = 8.02 | | | | | CV (%) = 9.0 | | | | |
| | 2013 | | | | | 2009-2013 | | | | |
| 0 | 1559 | 1919 | 2278 | 2311 | 2017 | 1466l | 2032k | 2433 | 2678 | 2152 |
| 50 | 1736 | 2282 | 2441 | 2664 | 2281 | 2163k | 2517 | 3033 | 3434 | 2786 |
| 100 | 1936 | 2509 | 2633 | 2988 | 2517 | 2344 | 3091 | 3706 | 4005 | 3286 |
| 150 | 2093 | 2650 | 3111 | 3366 | 2805 | 2559 | 3554 | 4156 | 4386 | 3664 |
| 200 | 2172 | 2645 | 3157 | 3414 | 2847 | 2642 | 3617 | 4237 | 4452 | 3737 |
| Mean | 1899D | 2401 | 2724 | 2949 | | 2235 | 2962 | 3513 | 3791 | |
| | LSD (0.05) L= 189.42, P = 169.42, L X P = NS | | | | | LSD(0.05) L = 87.92, P = 78.63, L x P=175.8 | | | | |
| | CV ( %) = 9.19 | | | | | CV (%) = 7.81 | | | | |

application of 2.2 t/ha lime and 30 kg/ha P which was on par with 1.65 t/ha lime and 20 kg/ha P application, suggesting increasing lime and P application beyond this rate is not worthwhile in terms of grain production (Figure 2).

Mean barley grain yield increment in the combined analysis at 1.65 t/ha lime coupled with 20 kg/ha P application was 183.5% cf. control. Similarly, in the initial year of 2009 grain yield increment was 274.0% cf. control, but in subsequent years grain yield advantage has steadily decreased to 224.0, 174.9, 164.0 and

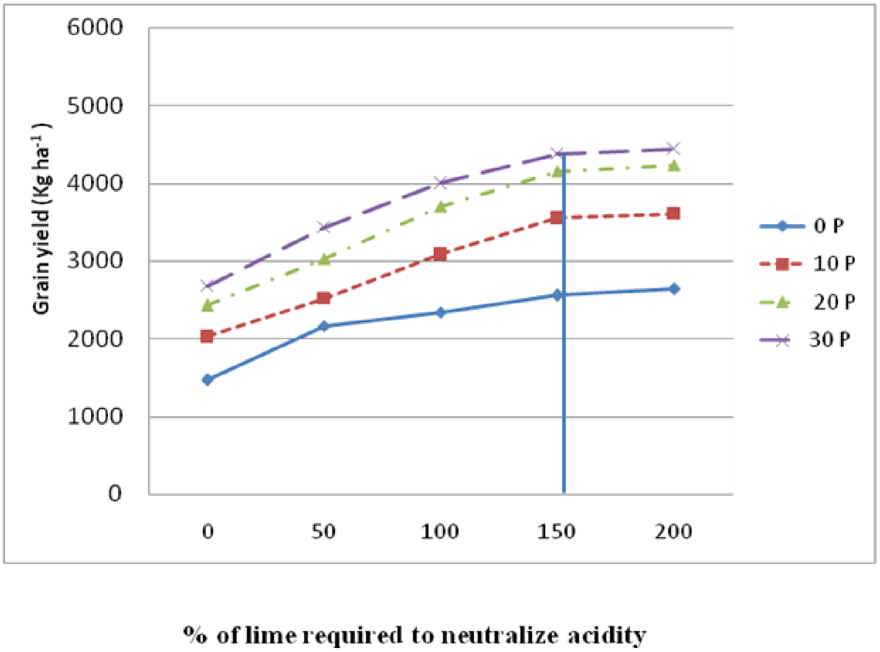

**Figure 2.** Effect of the combined use of lime and phosphorus fertilizers on the grain yield of barley Pooled over five years. The perpendicular line drawn shows optimum lime and P rate where maximum grain yield was achieved.

99.5% in 2010, 2011, 2012 and 2013, respectively. In a nutshell, the effect of lime on acid soil amelioration and barley grain yield were the highest during the initial four years, but in the final year grain yield was declined substantially. This yield reduction in the final year may indicate re-acidification of the soil. It is thus perceived that maximum amelioration of acid soils with lime could be achieved only after the elapse of four years since re-acidification would probably balance the slower amelioration reaction associated with less reactive lime particles. Meng et al. (2004) reported that crop yield increment at 50, 100, 150 and 200% lime application rates were lasted for 5, 7, 12, and 14 years, respectively.

The present findings are in agreement with Farhoodi and Coventry (2008), who reported that a year after lime application resulted in substantial yield increments of barely, wheat and faba beans (70 to 75%), and durum wheat at about 30%. Many researchers also revealed that lime application improved grain yield of crops (Liu et al., 2004; Achalu et al., 2012; Caires et al., 2005). According to Achalu et al. (2012), the increase in crop yield through application of lime may be attributed to the neutralization of Al$^{3+}$, supply of Ca$^{2+}$ and increasing availability of some plant nutrients like P. Furthermore, increase in grain yield with the application of lime is ascribed to its favorable effect on the chemical, physical, and microbial properties of the soil. Numerous authors (Scott et al., 1999; Farhoodi and Coventry, 2008) reported that application of lime at an appropriate rate brings about several chemical and biological changes in the soil, which is beneficial to improve crop yields in acid soils.

In the present study, the higher grain yield realized from calcitic lime application during the initial four years indicates fast dissolution reaction and high acid neutralization capacity of calcite lime. Similar behavior and performance were reported by other researchers about the fast dissolution and high reactivity of calcite (Hartwig and Loeppert, 1992), as well as its high effect (Bailey et al., 1989), and high solubility in acid (Merry et al., 1995).

## Changes in soil chemical properties

The results of soil analysis in 2009, 2011 and 2013 showed that lime application had significantly ($P<0.05$) increased soil pH and available P, while exchangeable acidity and Al$^{3+}$ had significantly reduced (Table 3). Soil pH was sharply increased by liming in the first year and thereafter slightly declined over years. Increasing lime application rates resulted in increase in soil pH values.

Application of 2.2 t/ha lime increased soil pH from the initial 4.8 to 5.9 in 2009, but on par with 1.65 t/ha lime applications with pH value of 5.66. Subsequently, after five years of lime application soil pH dropped to 5.3. Essentially, amelioration of soil acidity comprises detoxification of Al and Mn activity with the aid of lime amendment. Detoxification of Al can be achieved by increasing soil pH which in turn certainly result in

**Table 3.** Lime and its residual effects on soil pH, available P and exchangeable acidity at Bedi during 2009 - 2013 cropping seasons.

| Lime rates (t/ha) | Soil pH | | | Available P (ppm) | | | Exchangeable acidity (cmol/kg) | | | Exchangeable Al (cmol/kg) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2009 | 2011 | 2013 | 2009 | 2011 | 2013 | 2009 | 2011 | 2013 | 2009 | 2011 | 2013 |
| 0 | 4.52 | 4.96 | 4.60 | 10.65 | 12.35 | 12.27 | 1.32 | 1.32 | 1.34 | 1.19 | 1.19 | 1.21 |
| 0.55 | 5.30 | 5.33 | 5.11 | 14.23 | 12.54 | 12.24 | 0.46 | 0.41 | 0.80 | 0.41 | 0.37 | 0.73 |
| 1.10 | 5.53 | 5.65 | 5.20 | 16.00 | 15.54 | 14.11 | 0.20 | 0.21 | 0.44 | 0.19 | 0.20 | 0.40 |
| 1.65 | 5.66 | 5.67 | 5.24 | 17.36 | 17.18 | 16.78 | 0.14 | 0.12 | 0.35 | 0.13 | 0.12 | 0.32 |
| 2.20 | 5.91 | 5.88 | 5.30 | 18.92 | 17.31 | 16.76 | 0.10 | 0.11 | 0.35 | 0.10 | 0.11 | 0.32 |
| LSD0.05 | 0.30 | 0.128 | 0.114 | 1.33 | 1.45 | 1.71 | 0.04 | 0.02 | 0.04 | 0.04 | 0.02 | 0.04 |
| CV (%) | 6.89 | 2.83 | 2.72 | 10.51 | 11.75 | 14.39 | 13.06 | 6.70 | 8.36 | 13.07 | 6.88 | 8.41 |

decrease in Al solubility thereby minimizes its toxic effect on plants. However, after five years pH of the non-limed plot remained almost static and close to the initial level.

Exchangeable Al only becomes significant at pH levels less than 5.5 (Cregan, 1980) and the $Al^{3+}$ cation can be toxic to roots which is one of the major reasons that soil acidity can affect plant growth (Fenton and Helyar, 2007). The present findings are in agreement with Murata et al. (2002) who reported that application of lime at the rate of 2 t ha $^{-1}$ significantly increased topsoil pH values from 4.6 to 6.0. Meng et al. (2004) also showed soil pH increment of 0.64 to 2.14 units due to lime application which values were maintained for five years, while pH of the limed soil remained above the initial pH value up to 15 years.

In concomitance with increase in soil pH, available P level was also improved. Application of 2.2 t/ha of lime was on par with 1.65 t/ha in increasing available P in all years except in the initial year 2009. In a nutshell, application of lime improved P availability by 77.6, 40.0 and 36.6% as compared to no liming in 2009, 2011 and 2013, respectively. Sven et al. (2015) showed an increase in P availability with comparable amounts of added lime in field trials. Sarker et al. (2014) observed the highest available phosphorus in the soil with the application of lime at 2 t/ha measured with four soil test P extraction methods which probably explain the $Ca^{2+}$ and $Mg^{2+}$ in lime, displaced $Al^{3+}$, $Fe^{2+}$ and $H^{+}$ ions from the soil sorption sites resulting into reduction in soil acidity and P fixation. In general, on acid soils with a low initial pH, it can be expected that extractable P increases after lime application. This is due to the increase of the pH, causing desorption of P from Fe- oxides, Al-oxides and -hydroxides and the dissolution of Fe and Al-phosphates (Haynes, 1984).

Application of lime and its residual effect highly decreased exchangeable acidity and $Al^{+3}$ as the level of applied lime rates increased. Interestingly, all lime rates significantly ($P<0.01$) decreased exchangeable acidity from the initial level of 1.32 to 0.1 cmol/kg (Table 3). As could be expected, the effect of lime on exchangeable $Al^{3+}$ was almost similar to that of exchangeable acidity. Meng et al. (2004) reported similar findings with surface application of lime; acidity, particularly exchangeable $Al^{3+}$, was significantly reduced from 5.46 to 1.52 cmol/kg in the first year and these values are maintained up to five years which gradually increased to the original level after 14 years

## Relationships between grain yield and soil properties

Barely grain yield was positively correlated with soil pH and available P and inversely correlated with exchangeable acidity and exchangeable $Al^{3+}$ and the correlation was significant at $P<0.01$ (Table 4). However, grain yield was correlated most strongly with soil pH (r = 0.93), available P (r = 0.86), and exchangeable $Al^{3+}$ (r = -0.86). This illustrates that available P and soil pH and exchangeable $Al^{3+}$ are the most important yield limiting factor in acid soils.

Similarly, positive and significant correlation coefficients were observed among soil properties of each other. The data also revealed a strong and inverse correlation between exchangeable $Al^{3+}$ and $Ca^{2+}$ (r = -0.90). The positive correlation of soil pH with the grain yield implies that as the pH increases the yield also increase and as the

**Table 4.** Correlation of grain yield with soil properties under acid soil condition (Pearson Correlation Coefficients, N = 15).

| Parameter | pH | Available P | Exchangeable acidity | Exchangeable Al | Exchangeable Ca |
|---|---|---|---|---|---|
| Grain yield | 0.93** | 0.86** | -0.86** | -0.86** | 0.79** |
| pH | - | 0.86** | -0.92** | -0.92** | 0.85** |
| Available P | - | - | -0.85** | -0.85** | 0.93** |
| Exchangeable acidity | - | - | - | 0.98** | -0.90** |
| Exchangeable Al | - | - | - | - | -0.90** |

exchangeable acidity reduces, the plant roots performances are enhanced (Kamprath, 1984).

## Conclusion

Poor barley production in Bedi area has been associated with soil acidity viz. Al-toxicity and/or P deficiency. Application of lime and P fertilizer had significantly improved grain yield of barley and soil chemical properties. Barley grain yield increased progressively with higher lime and P application rates. The highest yield was 2.2 t/ha lime and 30 kg/ha P fertilizer application, but at par with 1.65 t/ha lime and 20 kg/ha P application. During the initial year of lime application, barely grain yield was increased by 274.0% cf. control, while after five years of liming grain yield increased only by 99.5%. This yield reduction after five years of liming may indicate re-acidification of the soil which necessitates re-liming of the soil.

Though there was no significant differences between 1.65 and 2.2 t/ha lime applications, both rates raised soil pH close to the optimum pH requirement of barley, but drastically decreased the exchangeable $Al^{3+}$ to a minimum level of 0.1 cmol/kg, which enhanced available P as a result of increased pH and decreased acidity level. Hence, lime application at the rate of 1.65 t/ha (150% of the lime requirement of the soils based on its exchangeable acidity) coupled with 20 kg/ha P fertilizer could serve as a reference to boost barley production in the study area and in similar areas with possible re-liming of the soils in every five years.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The authors appreciate the Ethiopian Institute of Agricultural Research (EIAR) for funding field and laboratory works. We would also like to thank the technical and the laboratory staff of the Holetta Research Center for their assistance in managing the field activity and soil analyses.

## REFERENCES

Achalu C, Heluf G, Kibebew K, Abi T (2012). Response of barley to liming of acid soils collected from different land use systems of Western Oromia, Ethiopia. J. Biodiv. Environ. Sci. 2(7):1-13.

Arshad MA, Gill KS (1996). Field pea response to liming of an acid soil under two tillage systems. Can. J. Soil Sci. 76:549-555.

Bailey JS, Stevens RJ, Kilpatrick DJ (1989). A rapid method for predicting the lime requirement of acidic temperate soils with widely varying organic matter contents. III. A lime-quality correction model. J. Soil Sci. 40:831-847.

Caires EF, Alleoni LRF, Cambri MA, Barth G (2005) Surface application of lime for crop grain production under a no-till system. Agron. J. 97:791-798.

Cregan P (1980). Soil acidity and associated problems – guidelines for farmers recommendations. Agricultural Bulletin No. 7, Department of Agriculture. NSW, Australia.

Central Statistical Agency (CSA) (2014). Agricultural Sample Survey Report on area and production of major crops. (private peasant holdings, Meher Season). V1. Statistical Bulletin. Addis Ababa, Ethiopia.

Ethiosis (2014). Soil fertility mapping and fertilizer blending. Agricultural Transormation Agency (ATA) Report, Ethiopia soil information system (Ethiosis). Ministry of Agriculture, Addis Ababa.

Farhoodi A, Coventry DR (2008). Field crop responses to lime in the mid-north region of South Australia. Field Crops Res. 108:45-53.

Fegeria NK, Baligar VC (2008). Ameliorating soil acidity of tropical oxisols by liming for sustainable crop production. Adv. Agron. 99:353-379.

Fenton G, Helyar K (2007). Soil acidification. In: Peter, EV, Charman and Brian, W. Murphy (eds). Soils-Their Properties and Management. 3rd edition. Oxford University Press, Melbourne.

Hailu R, Getachew A (2011). Potential and limitations of acid soils in the highlands of Ethiopia: a review. In: Mulat, B. and Grando, S. (eds.). Proceedings of the 2nd National Barely Research and Development Review Workshop. HARC, Holetta, Ethiopia pp. 103-112.

Hartwig RC, Loeppert RH (1992). A pH-stat procedure for evaluating reactivity of agricultural limestone. Soil Sci. Soc. Am. J. 56:302-308.

Haynes RJ (1984). Lime and phosphate in the soil–plant system. Adv. Agron. 37:249-315.

Kamprath EJ (1984). Crop Response to lime in the tropics. In: Adams, F. (eds.). Soil Acidity and Liming. Agronomy Madison, Wisconsin, USA 12:349-368.

Kochian LV, Hoekenga OA, Piñeros MA (2004). How do crop plants tolerate acid soils? Mechanisms of aluminum tolerance and phosphorous efficiency. Annual Review of Plant Biol. 55:459-493.

Liu DL, Helyar KR, Conyers MK, Fisher R, Poile GJ (2004). Response of wheat, triticale and barley to lime application in semi-arid soils. Field Crops Res. 90:287-301.

Meng C, Lu X, Cao Z, Hu Z, Ma W (2004). Long-term effects of lime application on soil acidity and crop yields on a red soil in Central Zhejiang. Plant Soil 265:101-109.

Merry RH, Hodge TJ, Lewis V, Jacka J (1995). Evaluation of liming materials used in South Australia. In: Date RA, Grundon, NJ, Rayment GE and Probert ME (eds.). Plant Soil Interactions at Low pH: Principles and Management. Kluwer Academic Publishers, Dordrecht, The Netherlands pp. 497-503.

Mesfin A (1998). Nature and Management of Ethiopian Soils. A.U.A.

Ethiopia P 470.

Mesfin A (2007). Nature and management of acid soils in Ethiopia. Addis Ababa, Ethiopia. P 99.

Murata MR, Hammes PS, Zharare GE (2002). Soil amelioration effects on nutrient availability and productivity of groundnut on acid sandy soils of Zimbabwe. Expl. Agric. 38:317-331.

Page AL, Miller RH, Keeney DR (1982). Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd edition. Soil Sc. Soc. Am., Madison, Wisconsin, USA P 1159.

Rebecca EH, Richard JS, Emmanuel D, Peter JH, Alan ER (2010). Effect of lime on root growth, morphology and the rhizosheath of cereal seedlings growing in an acid soil. Plant Soil 327:199-212.

Sarker A, Abul Kashem MD, Khan TO, Farzana A (2014). Evaluation of available phosphorus by soil test methods in an acidic soil incubated with different levels of lime and phosphorus. J. Soil Sci. 4: 103-108.

Scott BJ, Conyers MK, Poile GJ, Cullis BR (1999). Re-acidification and reclaiming effects on soil properties and wheat yield. Aust. J. Expt. Agric. 39:849-856.

Sven F, Heinz-Josef K, Klaus B (2015). Effect of liming central European loess soils on soil extractable phosphorus and potassium as determined by electro-ultrafiltration. Arch. Agron. Soil Sci. 61(6):725-736.

Temesgen D, Getachew A, Tesfu K, Tolessa D, Mesfin T (2011). Past and present soil acidity management research in Ethiopia. A review. Paper presented at the 2nd National Soil and Water Management Workshop', 28-31 January 2011, Addis Ababa, Ethiopia.

Wang JP, Harsh R, Guo-Ping Z, Neville M, Zhou MX (2006). Aluminium tolerance in barley (*Hordeum vulgare* L.): Physiological mechanisms, genetics and screening methods. J. Zheijang Univ. Sci. B 7:769-787.