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# Effects of lime and phosphorus fertilizer levels on growth and yield components of malt barley (*Hordeum distichum L.*) in Angolelana Tera District, North Shewa Zone, Ethiopia


## Abstract

Soil acidity and low availability of phosphorus (P) are among the major problems limiting crop production and productivity in the highlands of Ethiopia. An experiment was conducted under filed conditions to evaluate the effects of lime and P fertilizer on yield and yield components of malt barley (*Hordeum distichum L.*), and soil physic-chemical properties during 2016 main cropping season. The experiment comprised factorial combinations of three lime rates (0, 4 and 6ton/ha) and four P rates (0, 20, 30, 40kg/ha) in a randomized complete block design with three replications. The initial experimental site soil pH, exchangeable Al and available P was 5.01, 0.47cmolc/kg and 8.5mg/kg, respectively. Liming at rates of 4 and 6 ton/ha decreased exchangeable Al by 0.37 cmolc/kg, increased soil pH by 0.47 and 0.60 units and increased available P by 14.37mg/kg and 17.56mg/kg, respectively. The maximum (29.8qt/ha) and minimum (15.5qt /ha) grain yield was obtained by the combined application of 30kg P/ha with 4 ton lime/ha and the control, respectively. Lime and P fertilizer application had significant ($p<0.01$) effect on plant height and total biomass. Lime application (4ton/ha) gave the highest grain yield of malt barley. By addition of 20, 30 and 40kg P/ha, the grain yield increased by about 52.53, 69.31 and 70.74%, respectively, as compared to control. The combined application 4 ton/ha lime with 30kg P/ha and 6 ton/ha lime with 40kg P/ha increased the grain yield by 92.89% and 91.68%, respectively, as compared to the control. Combined application of lime and P are economically feasible to improve malt barley yield and yield components on acidic soils of the study area. Therefore, sustainable malt barley production on acid soils in the central highlands of Ethiopia should entail combined soil test based applications of both lime and P fertilizer.


**Keywords:** availability phosphorus, exchangeable al, exchangeable acidity, grain yield

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## Introduction

Barley (*Hordeum vulgare L.*) is one of the most important cereal crops in the world. Canada, Spain, Turkey, USA, Germany, France, Algeria, Ethiopia and Tunisia are the major barley producing countries. It is believed to have been cultivated in Ethiopia as early as 300BC. This long history of cultivation and large agro-ecological and cultural diversity in the country has resulted in large number of landraces and rich traditional practices.[1,2] In Ethiopia, among the cereals, barley is the fifth most important crop next to teff (Eragrostis tef), maize (*Zea mays L.*), sorghum (*Sorghum bicolor L.*) and wheat (*Triticum aestivum L.*).[3] It is the staple food grain for Ethiopian highlanders who manage the crop with indigenous technologies and utilize different parts of the plant for preparing various types of traditional food such as Kita, Kolo, Beso, Injera, local beverage called tela and as an important raw material for many industries[2] The major production of barley still largely depends on the traditional varieties and farming practices, which is also assumed to be one of the constraints accounting for its low yield. In addition, cultivation of barley in marginal areas with low soil fertility, drought in the semi arid and sub humid lowlands, soil acidity in the highlands and diseases and pests contribute to the low yield levels of the crop.[4,5] Because of this, the current production of malt barley in Ethiopia cannot fulfill the demands of the rapidly growing population and brewery factories.[3] The total estimated demand in 2014/2015 was around 279233.5 tons of which 35% are supplied from local barley productions. But the national average yield is low; with a mean of about 1,953,348 ton with productivity level of 19.65qt/ha.[3] Soil degradation is one of the challenges facing Ethiopian agriculture. One of soil chemical degradation challenging the highland soils of the country is soil acidity which can be caused leaching by high rainfall and plant uptake of cations such as calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$) and to lesser amount application of acidifying N fertilizers such as diammonium phosphate (DAP) and urea.[6] Soil acidity affects productivity of the soil through its effect on nutrient availability and toxicity by some elements like aluminum (Al) and manganese (Mn); most plant nutrient become more limited in supply and a few micronutrients become more soluble and toxic. These problems are particularly acute in humid tropical regions that have been highly weathered.[8,9] As soils become more acidic, particularly when pH drops below 5.5, it becomes increasingly difficult to produce different crops. High level of acidity can cause reduction of root growth, nutrient availability, affect crop protection activity,[9] reduction and total failure of crops and deterioration of soil physical properties. In general, it affects the biological, chemical and physical properties of soil, which in turn affects the sustainability of crop production.

Several agricultural practices have been recommended to overcome the problem of tropical acid soil infertility. Lime application is the most common method of reclamation of soil acidity. It can increase the soil pH, and modify soil physical, chemical and biological properties.[10] Hence lime is commonly called the foundation of crop production or 'workhorse' in acid soils.[11] Upon liming, a number of authors have reported decreases of Al in the soil solution as well as in the exchange complex, improved soil structure,[12] significant yield increases,[13] and increases in P uptake by plants, higher abundance and diversity of earthworms,[14] and improved organic matter decomposition and nutrient mineralization.[15] Acid soils have high P fixation capacity and applications of both lime and P fertilizer is frequently required for successful crop production. In addition to Al toxicity, low P availability to crops is also another factor that limits crop production on acidic soils.[16] Therefore, P deficiency and Al toxicity often occur simultaneously in many acid soils and are thought to be responsible for poor crop yields in acid soils. However, as the fixed P would be released for plant uptake after liming, the amount of additional P added has to be determined experimentally.[17]

The problem of soil acidity is considered to be one of the major bottlenecks to barley production in the highlands of Ethiopia. It is still a problem that has not been addressed in depth which resulted in decline of barely productivity in the country. To mitigate the negative effects of soil acidity and low soil fertility traditionally farmers practice fallow production system and soil burn with dung. Such practice seems to degrade the soil resource and microbial activities in the long-run and will not be sustainable due to severe soil erosion from bare fallows. In this production system, application of P fertilizer is not commonly practiced by farmers. To protect a potential loss of grain yield, at least a maintenance application of 10kg P/ha responsive sites that had soil test P levels above the critical levels.[18] However, it varies depending on the soil type, preceding crop, barley variety used and the prevailing environmental conditions. Therefore, $Al^{3+}$ toxicity and P deficiency are the two major factors limiting barley production on acid soils, and are partly responsible for the seasonal food shortages in some parts of the highlands of Ethiopia. Hence, liming and P fertilization appears to be amongst the most important operations required to boost barley productivity in the highlands of Ethiopia. Some research attempts were made at Areka District Southern Nation and National Regional State,[19] Tarmaber District North Shewa Zone of Amahara Regional State,[20] Guto-Gida District East Wolega Zone of Oromia Regional State[21] and Farta District North Western highlands area of Amhara Regional State.[22] In addition to aforementioned study in Ethiopia, currently there are different research activities going in to determine the liming factor and the interaction of lime and P fertilizers by the Federal and Regional Research Institutes.[7] However, there is shortage of information about the response of lime, fertilizer and the rates of these inputs for food and malt barley production in the highlands of Amhara Regional State, Angolelana Tera District Cheki kebele. In response to this field experiment was conducted with the following specific objectives:

a. Evaluate the effects of lime and P fertilizer on yield and yield components of malt barley (Hordeum distichum L.) on acidic soil of Angolelana Tera District, Cheki kebele under field condition,

b. Determine the effects of lime and P fertilizer on soil pH, exchangeable acidity, exchangeable Al, and P availability at different levels of lime and P on and

c. Assess the economical feasibility of lime and P fertilizer for small scale farmers.

## Materials and methods

### Description of study area

The study was conducted at Angolelana Tera District, North Shewa Zone of Amhara National Regional State, Ethiopia, Cheki kebele on farmer's field during 2016 the main growing season. It is found at longitude of 38° 37' 54.1"E and latitude of 11°40' 10.45"N. The altitude of the District ranges from 1700 to 3245 masl and the altitude of the specific site is 2812 masl with a flat topography. The mean annual temperature for Cheki keble is 13°C. The mean annual minimum and maximum temperature is 6.18°C and 19.8°C, respectively.[23] Based on Debre Berhan Agricultural Research Center (23), the rain fall follows a uni-modal annual distribution of one long summer season and one short spring season. The summer rain fall season (kiremt) extends from June to the middle of September. The spring (belg) season rain fall occurs between March and April. The mean annual minimum and maximum rain fall between 925 and 1240mm with a long term average of 1078mm (Figure 1).

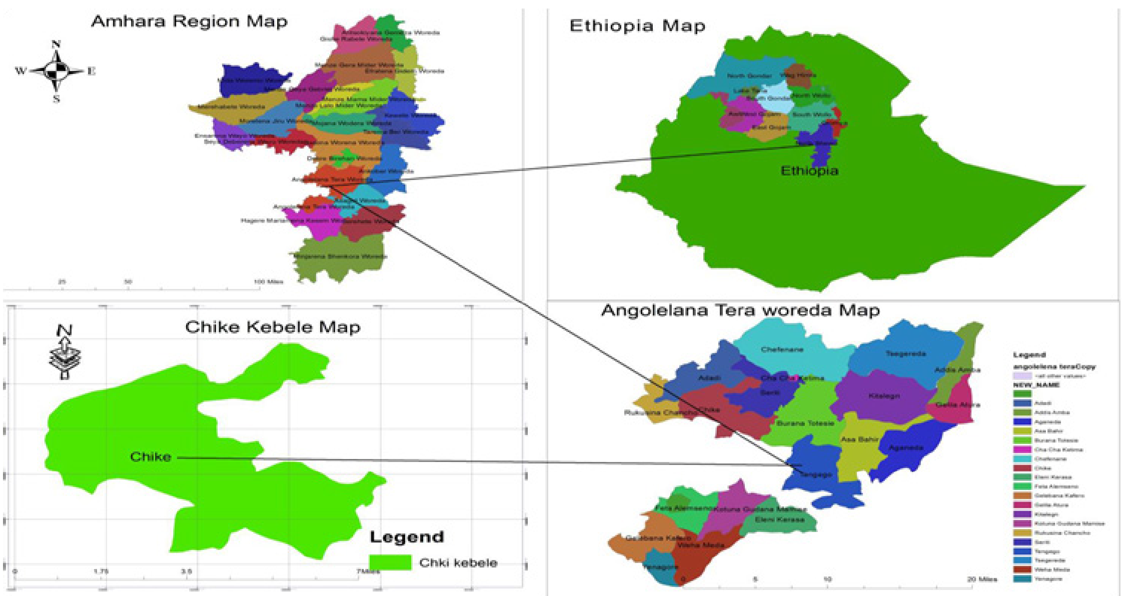


**Figure 1** Location map of Angolelana Tera district.

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## Experimental treatments, design and procedures

The experiment was laid down in randomized complete block design (RCBD) with three replication that consists of factorial combination of three levels of lime (0, 4 and 6tons/ha) to obtain target pH 5.5 and 6.0 which was determined by Shoemaker, McLean and Pratt (SMP) single buffer method and the four levels of P (0, 20, 30 and 40kg P/ha) in the form of TSP ($Ca(H_2PO_4)_2H_2O$) and it was applied by banding to the side of the seed. All lime rates were broadcasted uniformly and incorporated into the top soil (0-20cm) for each plot a month before sowing. Basal application of urea (150kg/ha) and KCl (100 kg/ha) was used as sources of N and K for all the plots, respectively (Table 1). Malt barley (*Hordeum distichum L.*) variety named holker used as a test crop planted in rows on a net plot size 2.6mx1.6m (4.16m$^2$) giving 9 rows of 3m length and 2m width with spacing 20cm. In order to avoid boarder effects, one outer most row 20cm from both sides of a plot and 20cm row length at both ends of each row of plot were left. Hence, 4.16m$^2$ (2.6mx1.6m) of a net plot size was used for data collection. In order to create good seed bed for proper crop growth, the experimental plots were cleared and ploughed three times according to farmers' conventional practice. Seeding was carried out based on the recommendation rate of 125kg/ha was drilled by hand. The full dose of P and K fertilizer and two-third dose of N fertilizer of the respective treatments were applied as band application to the side of the seed at sowing and the remaining one-third of N was side dressed at the mid tillering stage on the 34days after planting. During the different growth stages of the crop, the necessary recommended agronomic management practices were carried out.

**Table 1** Treatments and treatment combinations used in the study

| Applied P rate (kg/ha) | Applied lime rate (ton/ha) | | |
|---|---|---|---|
| | 0($L_0$) | 4($L_1$) | 6($L_2$) |
| 0($P_0$) | $P_0L_0$ | $P_0L_1$ | $P_0L_2$ |
| 20($P_1$) | $P_1L_0$ | $P_1L_1$ | $P_1L_2$ |
| 30($P_2$) | $P_2L_0$ | $P_2L_1$ | $P_2L_2$ |
| 40($P_3$) | $P_3L_0$ | $P_3L_1$ | $P_3L_2$ |

**Note** PxLy=x amount of phosphorus rate and y amount of lime rate, respectively.

## Pre sowing and post harvest soil sampling and preparation

Before the start of the study, a reconnaissance survey was conducted and general site information was recorded. Soil samples were randomly taken from the experimental site at a depth of 0-20cm using an auger and the samples were mixed thoroughly to produce 1 kg of one representative composite sample. After harvesting, 12 composite soil samples were collected from each type of treatment. The collected soil samples from the study area were bagged, labeled and transported to the Debre Berhan Agricultural Research Center Soil Laboratory for preparation and analysis of selected soil physical and chemical properties following standard laboratory procedures. 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, exchangeable acidity, and, cation exchange capacity (CEC), and pass through 0.5mm sieve for the analysis of soil organic matter (OM).

## Agronomic data collection

Data on plant basis was recorded from randomly taken 10 plants per plot, while the middle seven malt barley plant rows (2.64m$^2$) was used for data collection on plot basis. The collected data includes plant height, 1000 grain weight, grain yield, straw yield and total above ground biomass yield.

a. Plant height was measured from randomly sample 10 plants per plot at the late flowering stage.
b. Days to maturity were determined as the number of days from planting until 50% of the plants reach physiological maturity.
c. Grain yield (kg/ha) was recorded after harvesting from the central seven rows of the net plot. Grain yield was adjusted to 13.5% moisture level.
d. Straw yield (ton/ha) was recorded after harvesting and threshing from the central seven rows of the net plot.
e. Thousand grains weight were determined by taking 1000 grains randomly from the harvested net plot area.
f. Total biomass yield was measured after leaving the harvested plants in open air for about 10 days so that they attained constant weight. The above ground total biomass yield was calculated as the sum of the grain and straw yields.
g. Harvest index (HI) per plot was calculated as the ratio of the grain yield to the total above ground biomass yield.

## Pre sowing and post harvest soil physical and chemical properties determination

The pre sowing soil samples were analyzed following standard laboratory procedure as described below. Soil particle size distribution was analyzed by the Bouyoucos hydrometer method as described by Day.[24] The pH of the soil was measured potentiometrically using a digital pH-meter in the supernatant suspension of 1:2.5 soil-water ratios.[25] The soil lime requirement (LR) was determined by Shoemaker, McLean and Pratt (SMP) single buffer procedure.[26] Available P was determined calorimetrically using spectrophotometer after the extraction of the soil samples with 0.5M sodium bicarbonate ($NaHCO_3$) at pH 8.5 following the Olsen extraction method as described by Olsen.[27] Total exchangeable acidity was determined by saturating the soil samples with 1M KCl solution and titrated with 0.02M NaOH as described by Rowell []. From the same extract, 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.[28] The soil organic carbon content was determined following the wet digestion method as outlined and percent organic matter (OM) was obtained by multiplying percent organic carbon (OC) by 1.724. The potential CEC of the soil was determined from soil samples saturated with NH4+ at pH 7.0, subsequently replaced by K+ from a percolated 1M KCl solution. The excess salt was removed by washing with ethanol and the NH4+ that was displaced by K+ was measured using the micro-Kjeldahl procedure.[29] For the post harvest soil samples only pH, OM, CEC, exchangeable acidity, exchangeable Al and available P were determined using the procedures as described above.

## Statistical analysis

The agronomic data variation across each level of treatment/each plot was analyzed using Analysis of Variance (ANOVA) using SAS[30] statistical software version 9.2. Mean separation was done using least significant difference (LSD) test at 5% probability level.[31]

### Economic analysis

The mean grain yields for the lime and mineral P treatment combinations were subjected to discrete economic analysis using the procedure recommended by CIMMYT.[32] Economic optimum yield levels were identified using preliminary partial budgeting and dominance analysis. For the partial budget, analysis post harvest agronomic data were used and also account for percentage loss due to harvesting date and mechanism, storage, transport, etc. This was done by reducing the total yield by the recommended level of 10%, and arriving at the net yield. Then to determine the gross benefit by multiplying net yield by the field price (market price adjusted for any costs related to storage, transportation, etc.). Then all costs and benefits of each treatment were calculated separately to arrive at the net benefits of each treatment. This was helped researchers identify treatments with highest benefit for application of lime. Net benefits and costs that vary between treatments were used to calculate marginal rate of return to investment capital as to move from a less expensive to a more expensive treatment. Before conducting marginal analysis of all treatments, to conduct dominance analysis and draw the net benefit curve to identify and drop dominated treatments.[32,33] Economic analysis was carried considering only the purchasing cost of inputs as farmers normally use family labor to process, transport and apply lime and fertilizers to crop fields. Moreover, sensitivity analysis was made to see the sensitivity of the recommended rate when subjected to input and output price changes.

## Results and discussion

### Pre sowing soil physical and chemical properties

Pre sowing soil analysis result indicated that textural class of the soil is clay. The pH of the soil was 5.0 which is in the very strongly acidic soil reaction.[34] This indicated that the pH of soil is not suitable for malt barley production. The potential CEC (18.87cmolc/kg) of the soil was in moderate range. According to Tekalign[34] the organic carbon content of the soil was also in the moderate range. The available P of the study site was within moderate range.[27] Generally, the soil of the site had relatively high content of exchangeable acidity (0.98cmolc/kg) and Al (0.47cmolc/kg). These result indicated that applications of lime and P fertilizers is very important to increase soil pH and available P (Table 2).

**Table 2** Presowing physical and chemical properties of the experimental soils

| Parameter | Value |
|---|---|
| Textural class | clay |
| Sand (%) | 24 |
| Silt (%) | 34 |
| Clay (%) | 42 |
| Bulk density (g/cm³) | 1.3 |
| pH ($H_2O$) | 5.01 |
| Cation exchange capacity (cmolc /kg) | 18.87 |
| Exchangeable acidity (cmolc/kg) | 0.98 |
| Exchangeable Al (cmolc/kg) | 0.47 |
| Available phosphorus (mg/kg) | 8.5 |
| Organic carbon (%) | 2.55 |

### Effect of lime and phosphorus fertilizer on agronomic parameters and yield of malt barely

The mean squares for the different agronomic parameters and yield of the test crop as affected by application of different lime and P rates and their interactions are depicted in Table 3. Grain yield and 1000 grain weight had significant ($p \leq 0.05$) effect due to application of lime, P and for their interaction while plant height, total above ground biomass and straw yield were no significant ($p > 0.05$) difference by combined application of P with lime (Table 3).

**Table 3** Mean squares of agronomic parameters, as affected by main and interaction effects of P and L

| Source of variation | Df | PH | DM | TBY | TGW | ST | GY |
|---|---|---|---|---|---|---|---|
| Replication | 2 | 98.8ns | 18.11ns | 9356.69ns | 4.19ns | 12229.36ns | 4062.33ns |
| Phosphorus(P) | 3 | 176.31** | 394.78* | 1016552.22** | | 69633.58ns | 687731.59** |
| Lime(L) | 2 | 114.63** | 34.36ns | 1386107.96** | | 585410.36** | 179125.66* |
| P*L | 6 | 24.17ns | 16.92ns | 136605.11ns | 58.78** | 102396.69ns | 38793** |
| Error | 22 | 30.55 | 22.47 | 58376.5 | 2.71 | 49496.39 | 4943.99 |
| CV (%) | | 6.85 | 3.3 | 7.35 | 4.37 | 10.41 | 6.12 |
| F value | | 2.77 | 4.76 | 8.78 | 18.6 | 3.14 | 41.42 |

**Notes** GP, germination percentage; DH, days to heading; DGFP, days to grain filling period; PH, plant height; NFT, number of fertile tillers; DM, days to maturity; NSPS, number of seed per spike, SL, spike length; TBY, total biomass yield; TGW, toothed grain weight; GY, grain yield; ns, non significant; *, **, indicate significant difference at probability levels of 5%, and 1% and respectively.

### Plant height and day to maturity

Only sole application of P and lime had significant ($p \leq 0.05$) effect on the plant height and days to maturity (Table 3). The highest value of plant height was recorded in both P and lime applications rate (86.38cm), (82.6cm) in 30kg P/ha and 4 ton lime/ha application rate and the late maturing days were recorded (141.33), (133.55) without any P and lime application rate respectively (Table 4). Furthermore, the plant height and maturity of barely produced by applied at the rate of 30kg P/ha and 4 ton lime/ha exceeded that of all P rates while the lowest was obtained without P application (Table 4). The increase in plant height with increasing lime rates on acidic soils is highly likely related to the increase in soil fertility and reduction of the toxic concentration of Al and Mn. Liming might have reduced the detrimental effect of soil acidity on plant growth due to high concentration of H and Al ions in the acidic soils. Activities of exchangeable cations such as Ca2+, Mg2+ and K+, orthophosphate ($H_2PO_4$), nitrate ($NO_3^-$) and sulfate ($SO_4^{2-}$) anions with soil organic matter content and their availability to plant roots might be hampered by acidifying ions.[20,36–38]

## Total biomass and straw yield

Both lime and P applications had significant influence on total biomass (TBY) and straw yield (SY), but their interaction effect had no significant effect on both parameters. The highest TBY (7.42 ton/ha) and SY (4.86 ton/ha) were recorded in the treatment which received 6 ton lime/ha even though there was no significant difference with the application of 4 ton lime/ha (TBY=7.06 ton/ha and SY=4.54 ton/ha) (Table 4). The lowest TBY (6.05 ton/ha) and SY (3.96 ton/ha) were recorded in the treatment without lime. The application of 4 and 6 ton lime/ha increased TBY and SY by 16.53% and 22.59%, and 14.69%, 22.96% as compared to the control, respectively. In the case of P application the highest TBY and SY 7.40 and 4.64 ton/ha was recorded in the treatment which received 30kg P/ha. There was no significant difference among the TBY and SY obtained from 20kg P/ha (6.93, 4.57) ton/ha and 40kg P/ha (7.21, 4.35ton/ha), respectively (Table 4). The lowest TBY (5.84 ton/ha) and SY (4.25ton/ha) were recorded in the treatment that received no P.[20] Mean values followed by the same letters in each treatment showed not significantly different at $p<0.05$; CV= coefficient of variation *, **, ns indicate significant difference at probability levels of 0.05, and 0.01 and non significant difference, respectively. Total biomass yield and SY increased by 18.66%, 26.85%, 23.57% and 7.61%, 9.31%, 2.63% in compare to control, respectively (Table 4). The result showed that lime increases availability of residual and applied P for the growth of plants, especially at higher doses. This is in agreement with,[20] who indicated that increased lime level increased total dry matter irrespective of cultivars. Significant increases in plant height, tillering, spike length, number of seed per spike and grain yield contributed to increase TBY from P application. Biomass yield of food barley was significantly increased by application of lime and P fertilizes.[36]

**Table 4** Effects of P and lime rates on plant height (cm), day to maturity and biomass and straw yield (ton/ha)

| Lime application (ton/ha) | PH | DM | BY | SY |
|---|---|---|---|---|
| 0 | 77.20$^{b}$ | 141.33$^{a}$ | 11.69$^{b}$ | 7.70$^{b}$ |
| 4 | 82.60$^{a}$ | 144.41$^{a}$ | 13.71$^{a}$ | 8.87$^{a}$ |
| 6 | 82.28$^{a}$ | 144.68$^{a}$ | 14.52$^{a}$ | 9.27$^{a}$ |
| CV (%) | 6.85 | 3.3 | 7.35 | 10.4 |
| $LSD_{(0.05)}$ | 4.67 | 1.01 | 204.56 | 188.36 |
| Mean | 81.66 | 143.27 | 13.3 | 8.61 |
| P application (kg/ha) | | | | |
| 0 | 78.34$^{cb}$ | 133.5$^{b}$ | 11.3$^{b}$ | 8.1$^{a}$ |
| 20 | 81.60$^{ab}$ | 144.88$^{a}$ | 13.3$^{a}$ | 8.9$^{a}$ |
| 30 | 86.38$^{a}$ | 148.22$^{a}$ | 14.1$^{a}$ | 9.0$^{a}$ |
| 40 | 76.12$^{c}$ | 146.44$^{a}$ | 13.7$^{a}$ | 8.5$^{a}$ |
| Lime | ** | ns | ** | ** |
| Phosphorus | ** | * | ** | ns |
| P*L | Ns | ns | ns | ns |
| CV (%) | 6.85 | 3.31 | 7.35 | 10.41 |
| $LSD_{(0.05)}$ | 5.4 | 4.63 | 236.21 | 217.5 |

Mean values followed by the same letters in each treatment showed not significantly different at $p<0.05$; CV =coefficient of variation *, **, ns indicate significant difference at probability levels of 0.05, and 0.01 and non significant difference, respectively.

## Thousand grains weight

The 1000 grains weight measured at seed moisture content of 13.5% had significant ($p\leq0.05$) effect due to the combined application of P and lime (Table 5). The weight of 1000 grain was ranged from 32 to 44.33gm for the interaction effects of P and lime rates (Table 6). Shiferaw[36] also reported that the interaction of P and lime on 1000 seed weight had significant effect. Mean values followed by the same letters in each treatment showed not significantly different at $p<0.05$; CV=coefficient of variation *, **, ns indicate significant difference at probability levels of 0.05, and 0.01 and non significant difference, respectively

**Table 5** Mean thousand grains weight under the interaction effect of P and lime and P application

| P application (kg/ha) | Lime application (ton/ha) | | | Mean |
|---|---|---|---|---|
| | 0 | 4 | 6 | |
| 0 | 32.00$^{g}$ | 34.00$^{fg}$ | 33.66$^{fg}$ | 33.22 |
| 20 | 32.00$^{g}$ | 36.00$^{fe}$ | 37.33$^{de}$ | 35.11 |
| 30 | 40.66$^{bc}$ | 44.33$^{a}$ | 39.33$^{dc}$ | 41.44 |
| 40 | 35.33$^{fe}$ | 43.66$^{a}$ | 42.66$^{ba}$ | 40.55 |
| Mean | 34.99 | 39.49 | 38.24 | |
| P value | ** | | | |
| CV (%) | 4.37 | | | |
| $LSD_{(0.05)}$ | 2.78 | | | |

Mean values followed by the same letters in each treatment showed not significantly different at $p<0.05$; CV = coefficient of variation *, **, ns indicate significant difference at probability levels of 0.05, and 0.01 and non significant difference, respectively.

**Table 6** Mean grain yield (qt/ha) under the interaction effect of lime and P application

| P application (kg/ha) | Lime application (ton/ha) | | | Mean |
|---|---|---|---|---|
| | 0 | 4 | 6 | |
| 0 | 15.5$^{cb}$ | 15.9$^{ca}$ | 16.4$^{ca}$ | 15.93 |
| 20 | 19.3$^{b}$ | 26.5$^{ba}$ | 27.0$^{ba}$ | 24.26 |
| 30 | 22.7$^{ba}$ | 29.8$^{a}$ | 29.4$^{a}$ | 27.3 |
| 40 | 23.3$^{ba}$ | 28.5$^{a}$ | 29.6$^{a}$ | 27.13 |
| Mean | 20.2 | 25.18 | 25.6 | |
| Lime | * | | | |
| Phosphorus | ** | | | |
| P*L | ** | | | |
| CV (%) | 6.13 | | | |
| $LSD_{(0.05)}$ | 68.74 | | | |

Mean values followed by the same letters in each treatment showed not significantly different at $p<0.05$; CV = coefficient of variation *, **, ns indicate significant difference at probability levels of 0.05, and 0.01 and non significant difference, respectively.

## Grain yield and harvest index

The main interaction application of lime with P fertilizer had high significant effect on malt barley grain yield at the rates of 0/4, 0/6 and 20/0), (0/0, 30/4, 30/6, 40/4, 40/6) and (20/0, 30/4, 30/6, 40/4, 40/6) kgP/ha and ton lime/ha respectively from all other interaction and between all other interaction were significant ($p<0.05$) difference with each other (Table 7). The application of lime with P fertilizers at the rates of 20/4, 20/6, 30/4, 30/6, 40/4 and 40/6 kg P/ha and ton lime/ha respectively, increased the grain yield of malt barley by 28.5%, 71.4%, 74.5%, 92%, 89.9%, 84.6% and 91.6% respectively compared with the control (Table 7). Similarly, (20, 36, 39) reported that the yield of barley increased at increasing the level of lime with P fertilizer application rates. The maximum (29.8qt /ha) and minimum (15.5qt/ha) yield and was recorded at applied rate of 30kg P/ha with 4 ton lime/ha and the control, respectively.

**Table 7** Mean harvest index under the interaction effect of lime and P application

| P application (kg/ha) | Lime application (ton/ha) | | | Mean |
|---|---|---|---|---|
| | 0 | 4 | 6 | |
| 0 | 24.77ca | 27.19ca | 25.44ca | 27.47 |
| 20 | 28.78ba | 34.81ba | 37.81ba | 33.8 |
| 30 | 38.80a | 38.76a | 35.58a | 37.71 |
| 40 | 39.87a | 40.48a | 38.56a | 39.64 |
| Mean | 34.31 | 35.31 | 34.35 | |
| Lime | ** | | | |
| Phosphorus | ** | | | |
| P*L | ** | | | |
| CV (%) | 6.98 | | | |
| $LSD_{(0.05)}$ | 2.36 | | | |

Mean values followed by the same letters in each treatment showed not significantly different at $p<0.05$; CV=coefficient of variation *, **, ns indicate significant difference at probability levels of 0.05, and 0.01 and non significant difference, respectively.

In this study successive applications of P increased grain yield and yield components, and counteracted Al toxicity by precipitating exchangeable Al3. This could be the reason why large applications of phosphate fertilizers to acid soils overcome the toxic effects of Al and thereby improve growth of plants. A major characteristic of Al toxicity is an inhibition of the uptake and translocation of P by plants. Thus, liming acid soils often increases P uptake by plants by decreasing A1 toxicity rather than by an effect on soil P availability.[40] After a reviewing of liming on phosphate availability,[41] concluded that high amounts of phosphates added to acid soils reduce the injurious effects of Al ions by precipitating it from the soil and supplying sufficient phosphate for plant metabolic activity. However, the classical explanation of increased phosphate availability following liming is that in the short-term, the increased pH results in the hydrolysis of strengite and variscite with the release of phosphate ions into soil solution.[42] In this study, non amended soil produced the lowest harvest index on soils from all treatments. The increased percent harvest index obtained on soils from all treatments treated with different lime and P rate as compared to the respective non amended ones is highly likely associated with reduction of concentration of exchangeable acidity and enhancement of exchangeable bases, CEC and available P of the soils. The maximum percent harvest induce 40.48% of the malt barley was obtained from treatments application 40kg P/ha with 4ton/ha lime; however, it was 39.87% on treatments application of 40kg P/ha without lime (Table 7). The maximum total biomass and final grain yield obtained under the applied lime with P rate might be an important contributing factor for high malt barley harvest index at 6ton/ha lime rate and 30kg P/ha with 4 ton lime/ha lime, respectively (Table 6 & 7). Mean values followed by the same letters in each treatment showed not significantly different at $p<0.05$; CV = coefficient of variation *, **, ns indicate significant difference at probability levels of 0.05, and 0.01 and non significant difference, respectively

Mean values followed by the same letters in each treatment showed not significantly different at $p<0.05$; CV=coefficient of variation *, **, ns indicate significant difference at probability levels of 0.05, and 0.01 and non significant difference, respectively. Application of lime and P fertilizer brought a change on pH, exchangeable acidity; exchangeable Al and available P at the end of this filed experiment. The soil pH varied from 5.04 to 5.86; exchangeable acidity from 0.96 to 0.14cmolc/kg, exchangeable Al from 0.37 to 0.0cmolc/kg, the Olsen extractable P varied from 13.3 to 31.9mg/kg and CEC from 18.96 to16.84cmolc/kg. The mineral P fertilizer application has no effect on the pH, CEC, exchangeable acidity and exchangeable Al compared to the control. However, application of 20, 30 and 40kg P/ha increased the Olsen extractable P by 9.04, 11.32, 6.08mg/kg (67.9, 85.1, 45.7%) as compare to control. The highest lime rate (6ton/ha) increased the pH from 5.07 to 5.64 and reduced the exchangeable acidity from 0.96 to 0.19cmolc/kg and exchangeable Al from 0.37 to 0.0cmolc/kg and Olsen extracted P from 8.95 to 15.66. Thus, the lime application decreased the percentage of Al saturation from 38.54% in to 0%.[43] Also reported that treated acidic soils with various liming materials for one month generally reduced exchangeable acidity among which $CaCO_3$ used as a liming material showed up to 68% reduction of exchangeable acidity of the soils. The lime rates 4ton/ha also increased the pH from 5.07 to 5.51 and reduced the exchangeable acidity from 0.96 to 0.35cmolc/kg; exchangeable Al from 0.37 to 0.0cmolc/kg and Olsen extracted P from 8.95 to 15.66mg/kg (Table 8).

**Table 8** Soils physical and Chemical properties in the experimental field of Angolela Tera District after harvesting, 2016

| Treatment | pH | OC | Ex. Ac | Ex. Al | Ex. H | Av. P | CEC |
|---|---|---|---|---|---|---|---|
| Control | 5.04 | 2.3 | 0.96 | 0.37 | 0.59 | 8.95 | 18.76 |
| 4ton lime | 5.51 | 2.12 | 0.35 | 0 | 0.35 | 15.66 | 17.29 |
| 6ton lime | 5.64 | 2.07 | 0.19 | 0 | 0.19 | 16.77 | 17.11 |
| 20 kg P | 5.07 | 2.47 | 0.89 | 0.31 | 0.58 | 19.38 | 18.96 |
| 20/4 P/lime | 5.59 | 2.21 | 0.18 | 0 | 0.18 | 20.05 | 18.02 |
| 20/6 P/lime | 5.86 | 1.78 | 0.14 | 0 | 0.14 | 26.94 | 17.21 |
| 30 kg P | 5.09 | 2.49 | 0.78 | 0.34 | 0.44 | 22.34 | 18.67 |
| 30/4 P/lime | 5.44 | 2.31 | 0.32 | 0 | 0.32 | 28.34 | 17.09 |
| 30/6 P/lime | 5.79 | 2.27 | 0.16 | 0 | 0.16 | 30.43 | 16.84 |
| 40kg P | 5.11 | 2.23 | 0.74 | 0.28 | 0.46 | 24.62 | 18.82 |
| 40/4 P/lime | 5.49 | 2.08 | 0.25 | 0 | 0.25 | 29.23 | 17.26 |
| 40/6 P/lime | 5.72 | 2 | 0.18 | 0 | 0.18 | 31.9 | 17.08 |
| **Mean** | **5.45** | **2.18** | **0.43** | **0.11** | **0.32** | **23.24** | **17.76** |

**Notes** OC, organic carbon; Ex.Ac, exchangeable acidity; Ex.Al, exchangeable aluminum; Ex.H, exchangeable hydrogen; Av.P, available P; CEC, cation exchange capacity

Generally soil pH increased in a linear fashion with increasing lime rate. The increase was highest with applications of the maximum rate (6t/ha) of lime. When lime is added to acid soils that contain high Al3+ and H+ concentrations, it dissociates into Ca+2 and OH- ions forming Al3+ hydroxide and water, thereby increase soil pH in the soil solution. Meanwhile, applications of the highest rate of lime appreciably reduced soil exchangeable Al3+ which was 0.47Cmol/kg at the start of the experiment to 0Cmol /kg after 6 month of soil analysis. [22,44,45] have also reported that liming raises soil pH, base saturation, and Ca and Mg contents, and reduces Al3+ concentration.

### Economic analysis

Net present value (NPV) was positive for all tested treatments including the control in the study area (Table 9). In all treatments the net benefits analysis of lime and P application showed that a positive value leading to rejection of null hypothesis (HO) that lime technologies were less cost efficient to enhance soil fertility, crop yields and finally livelihoods within short time. Accordingly these results suggested that all treatments at Angolelana Tera District were economically feasible as the net benefit values (NBV) were greater than zero (NBV>0). The maximum (16823.56 birr) and minimum (651.86 birr) NBV were obtained from 4ton lime/ha with 30kg P/ha and 6ton lime/ha without P. Lime application rate 4, 6ton/ha without P, 6 ton/ha with 20kg P/ha, 6ton/ha with 30kg P/ha, and 6 ton/ha with 40 kg P/ha was recorded negative and the other levels of lime was positive response as compare to control. The maximum marginal rate of return (MRR) (3613.6 birr (27.35%)) was recorded at rate of 4ton lime/ha with 30kg P/ha as compare to control. The result was inconformity with the findings of [20,36]

**Table 9** Partial budget analysis for the mean grain yield of malt barley

| Treatments | Gross benefit birr/ha | TVC | Net benefit | MRR% |
|---|---|---|---|---|
| Control | 15755.72 | 2545.73 | 13209.96 | |
| 4ton lime | 16208.92 | 11545.73 | 4663.22 | - |
| 6ton lime | 16697.59 | 16045.73 | 651.86 | - |
| 20 kg P | 19721.2 | 3894.58 | 15826.62 | |
| 20/4 P/lime | 27005.85 | 12894.58 | 14111.15 | 6.82 |
| 20/6 P/lime | 27496.44 | 17394.58 | 10101.83 | - |
| 30 kg P | 23129.75 | 4569.01 | 18560.74 | |
| 30/4 P/lime | 30392.61 | 13569.01 | 16823.56 | 27.36 |
| 30/6 P/lime | 33003.61 | 18069.01 | 11863.47 | - |
| 40kg P | 18239.15 | 5243.43 | 18549.54 | |
| 40/4 P/lime | 29589.43 | 14243.43 | 14846.26 | 12.38 |
| 40/6 P/lime | 32320.41 | 18743.43 | 11457.94 | - |

**Notes** TVC, total variable cost, MRR%, marginal rate of return as compared to control

## Conclusion

The current experiment confirmed and suggested that lime is essential but must be complimented with balanced plant nutrients in order to get adequate malt barley yield in the study area. Hence it is economically feasible to improve malt barley yield and yield components on acidic soils of the study area by combined use of lime and mineral P fertilizer. Therefore, soil test based lime and P application can be used for the sustainable production of malt barley on acidic soils in Ethiopia.

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## Conflicts of interest

Authors declare that no competing of interest exists.

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