ORIGINAL ARTICLE

Applications of lime and phosphorus fertilizer to malt barley for improved yield and soil acidity at Welmera district, Ethiopia

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ABSTRACT

Soil acidity is expanding in scope and magnitude across different regions of Ethiopia. About 43% of total arable land in Ethiopia is affected by soil acidity. Soil P deficiency is also a major constraint to increase crop yields under acidic soil conditions. Appropriate rate of lime and P fertilizer addition is an important strategy for improving crop growth in acid soils. Accordingly, this investigation was undertaken to study yield response of malt barley to lime and P fertilizer application. The experiment was conducted in 2018 at Holeta Agricultural Research Center (HARC), Robgebeya (RG) and Watabacha Minjaro (WM) Acidic fields that were not reclaimed with lime for the last five years were selected and sampled. The experimental treatments comprised of six rates of lime (0, 1.56, 2.34, 3.12, 3.9, and 4.68 t ha^{-1}) and three rates of P (0, 16.5 and 33 kg ha^{-1}) arranged in factorial RCBD with three replications. Soil and agronomic data were collected and analyzed following standard procedures. Results showed that the soil pH increased and exchangeable acidity reduced after amending the soil with lime. Interaction of lime by P fertilizer at the rate of 3.12/16.5, 3.12/33 and 3.12/16.5 (t ha^{-1}/kg ha^{-1}) at HARC, RG and WM, respectively resulted in statistically better yields compared to the other treatment combinations. Therefore, it is recommended that 3.12 t ha^{-1} lime by 16.5 kg ha^{-1} P fertilizer are good combination for production of malt barley in Welmera District.

Key words: *Acid soil, Available P, Exchangeable acidity, Grain yield, Growth attribute, Soil pH.*

INTRODUCTION

Barely (*Hordeum vulgare* L.) is one of the most important food, feed and industrial crop produced in the world. It was sixth both in terms of quantity produced and in area cultivated by cereal crops in the world after rice, maize, sorghum, millet and wheat in 2017 (FAOSTAT, 2019). In Ethiopia based on area of production, barley ranks fifth of all grains, but fourth based on yield per unit area. It covers 7.51% of the land under grain crop cultivation with a yield of 2.16 t ha^{-1} (CSA, 2018). Although, barley's importance as food and industrial crop for the inhabitants of the highlands of Ethiopia, there are several factors affecting its production to attain potential productivity.

Soil acidity is among the environmental factors contributing to crop yield reduction in the country in general and that of barely in particular. Behailu (2015) and Mesfin (2007) reported that, soil acidity is expanding in scope and magnitude across different regions of Ethiopia, where 43% of total arable land is affected by soil acidity. About 27.7% of these soils are dominated by moderate to weak acid soils 4.5-5.5, and 13.2% by strong acid soils (pH in KCl) <4.5 (Schlede, 1989; Mesfin, 2007). This huge area is needed for crop production to meet the demand of food, feed and industrial materials.

Soil acidity is a principal obstacle for crop production in many regions of the world (Sumner and Noble, 2003). It is a serious process of agricultural land degradation, which leads to decrease in soil reaction and the increase in soil acidity (Behera and Shukla, 2015). Abundant precipitation and prolonged intensive leaching deplete basic cations (such as Ca^{2+}, Mg^{2+}, K^+ and Na^+) adsorbed on negatively charged sites and are replaced by protons (H^+) originating from H_2O, H_2CO_3, or organic acids (van Breemen *et al.*, 1984). The problem is aggravated through continuous cropping and use of acidifying fertilizers; applying excessive NH_4^+ or R-NH_2 based fertilizers (Xu *et al.*, 2002; Schroder *et al.*, 2011). This attributes to low soil pH which severely affects nutrient solubility and particularly enhance phosphorus sorption and precipitation with Al and Fe (Takow *et al.*, 1991; Hue, 1992).

The releases of Al^{3+} ions from mineral structure occupy soil cation exchangeable sites to form exchangeable Al^{3+} (Huang, 1997), which is the main form of exchangeable acidity in acidic soil (Yu, 1997). Excess Al^{3+} ions tend to accumulate in plant roots and thereby prevent P, Mo and other ions translocation to the tops from the roots, as shown by retarding root elongation and overall crop development (Kochian *et al.*, 2004).

Soil P deficiency is a major constraint to increase crop yields in tropical and subtropical regions (Stangel and von Uexku ll, 1990), where soil acidity the main constraint to crop production. To maintain production levels, P must be added to the soil plant system as mineral fertilizer to replenish what is removed by harvested crop parts (Vlek *et al.*, 1997). Nevertheless, under acidic conditions, the applied phosphorus reacts with Fe and Al oxides/hydroxides to form insoluble phosphates (Kamprath, 1984). Liming of acid soils can increase soil pH, P availability and alleviate Al toxicity to plants and thus maintain a suitable environment for growth of a variety of crops (Lollato *et al.*, 2013; Geremew *et al.*, 2015; Mamedov *et al.*, 2016; Getachew *et al.*, 2017). Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to increase available P in soils. Appropriate rate of lime and P fertilizer are therefore important strategies for improving crop productivity on acid soils. Nevertheless, there are no experiments conducted to see the effects of lime and P fertilizer on malt barley yield and yield components in Welmera district. Therefore; this investigation was undertaken to study response of malt barley yield to lime and Phosphorus fertilizer at Welmera district central high land of Ethiopia.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in 2018 production year in Oromia national regional state in Welmera District of Holeta Agricultural Research Center (HARC), Robgebeya (RG) and Watabacha Minjaro (WM) found 40, 52 and 25 km, respectively, North West of Addis Ababa on the main road to Ambo. HARC is situated at 9^0, 3.528′ N latitude, 38^0, 30.742′ E longitude with altitude of 2374 meter above sea level (masl), RG at 9° 8.10′ N latitude, 38° 26.415′ E longitude with an altitude of 2628 masl., and WM at 9° 6.040′ N latitude and 38° 36.091′ E longitude, altitude of 2702 masl. (Fig.1). According to mean decadal weather data (2009-2018) the district receives mean annual rainfall of 878.4 mm, annually with minimum, maximum and mean monthly temperatures of 6.5, 23.1 and 14.8^0C, respectively with 57.6% mean relative humidity (Fig. 2).

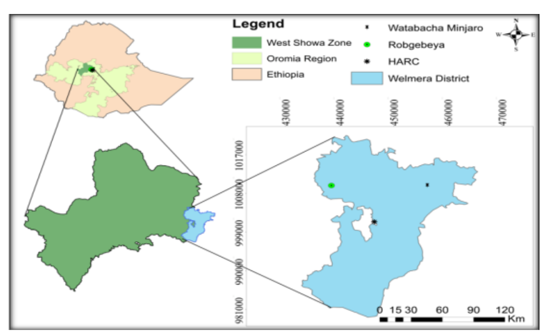

Figure 1. Map of Welmera District with its study site.

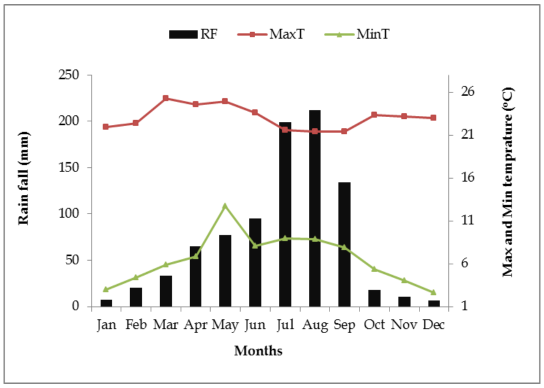

Figure 2. Average decadal weather trend at Holeta Agricultural Research Center (2009-2018).

Soil Sampling and analysis

Acidic fields that have not been previously reclaimed with lime for the last five years were selected. Soil samples were collected at a depth of 0-15 cm at randomly marked sampling points and composited to 0.5 kg. The soil samples were air-dried, ground and allowed to pass through 0.5 mm sieve for N and OC and a two mm sieve for the other soil parameters analysis. Physicochemical properties of soil such as texture, pH, cation exchange capacity (CEC), exchangeable acidity (Ac), exchangeable Aluminum (exAl), exchangeable bases (Ca, Mg, Na and K), organic carbon (OC), total nitrogen (TN), available phosphorus (avail. P) were analyzed for characterization of the fertility status of the experimental sites. Similarly, soil samples were collected on plot bases at harvesting.

Soil particle size distribution was analyzed by the hydrometer method (Bouyoucos, 1962). The pH of the soil was measured potentiometrically using a pH meter in the supernatant suspension of 1:2.5 soils to liquid ratio of water (Van Reeuwijk, 1992). The Walkley and Black (1934) wet oxidation method was used to determine soil OC. The TN content of the soil was determined by digestion procedure of the Kjeldahl method (Bremner and Mulvaney, 1982). Available P was extracted using the standard Bray-II (Bray and Kurtz, 1945) method.

Exchangeable bases (Ca, Mg, K and Na) were determined after extracting the soil samples by 1N neutral ammonium acetate (1N NH_4OAc) solution adjusted to pH 7.0. Exchangeable bases in the extract were measured by atomic absorption spectrophotometer (AAS) (Okalebo *et al.*, 2002). The CEC was determined from the ammonium acetate saturated samples through distillation and measurement of ammonium using the modified Kjeldhal procedure as described by Okalebo *et al.* (2002). Exchangeable acidity (Al and H) and exchangeable Al were determined by saturating the soil samples with 1N KCl solution and the filtrate were titrated with 0.02N NaOH and 0.02N HCl, respectively as described by Rowell (1994).

Experimental design, treatments and experimental setup

Field experiments were conducted to evaluate the responses of malt barley to lime and phosphorus fertilizer on acidic soils. The experimental setup was six rates of lime and three rates of P combined in factorial RCBD with three replications. The lime rates were control (0), 1.56, 2.34, 3.12, 3.9 and 4.68 t ha^{-1}. the lime amounts set were based on study by Geremew *et al.* (2020) determined using different determination methods to adjust the soil pH 6 to the requirement of the crop, that was 3.12 t ha^{-1}. Lime source used was $CaCO_3$, the purity was 95.5% with relative neutralizing value of 85.6. Phosphorus rates were control (0), 16.5 and 33 kg ha^{-1} P based on package of NPS fertilizer which contains 38 P_2O_5 in 100 kg of the fertilizer. Nitrogen fertilizer applied equally to all plots based on area recommendation (54 kg ha^{-1}) considering the N amount in NPS. The plot area was 2 by 2.5 m^2 having 10 rows with 20 cm between rows. The lime ($CaCO_3$) was applied 30 days before sowing by broadcasting uniformly on the plots, P was applied by banding at planting and malt barley variety IBON143/3, developed at HARC from ICARDA germplasm and released in 2012 used.

Plant sampling and analysis

Description of data collection procedures according to Anderson *et al.* (2002) on agro-morphological and yield attributing traits of malt barley on plot and plant basis is presented in (Table 1). Agronomic data such as planting date, days to physiological maturity, biological and grain yields, spike length, number of spikelets per spikes were recorded

Table 1. Description of malt barley data collection methods

Parameters	**Description**
Plant Height	Measured as a height in cm from soil surface to the tip of the spike excluding the awns at maturity and expressed as an average of ten plants per plot
DTPH*	Recorded as number of days from sowing to the stage when 50% of the plants in central rows of a plot have reached maturity
Spikes Length	Spike length of main tiller measured in cm from base to tip excluding the awns and expressed as an average of ten plants in a plot
NSPS**	Recorded by counting the number of spikelets on each spike on main tiller of each and expressed as an average of ten plants in a plot
Biomass Yield	Determined by weighing the total air-dried above ground biomass harvested from the central rows and expressed in kg ha^{-1}.
Grain Yield	Grain yield in kilogram of the central rows adjusted to 12% moisture content expressed in kg ha^{-1}

*DTPM - Days to physiological maturity, NSPS**- Number of spikelets per spike.

Data analysis

The data were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS, 2003). The difference among significant treatment means were tasted using least significant difference (LSD) at 5% level of significance. Before combined analyses test of homogeneity of error variance and normality was checked.

RESULTS AND DISCUSSIONS

Properties of the study area soil

Selected soil properties before sowing

Soil analysis results are indicated in Table 2. According to rating by Tekalign *et al.* (1991) the soils of the study areas were strongly acidic at HARC and RG and very strongly acidic at WM; hence being unsuitable for plant growth. The soil OC was very low and TN was medium as rated by Tekalign *et al.* (1991), while very low in avail. P as rated by Jones (2003). Soil CEC was moderate according to Hazelton and Murphy (2007) at all sites. Exchangeable Ca was moderate at all sites while Mg was moderate at HARC and RG, but low at WM. Exchangeable K content was high according to rating by FAO (2006), 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 2), which can depress plant growth and affects crop productivity.

Table 2. Selected soil physico-chemical characteristics in Welmera District before lime application and sowing

Sites	pH-H_2O	Particle size distribution			Textural class	AP	OC	TN	PBS	CEC	Ac	exAl	Ca	Mg	K
	1:2.5	Clay	Silt	Sand		(ppm)	%			cmol(+)kg^{-1}soi					
HARC	4.93	50	35	15	Cl	7.12	1.52	0.16	88.9	21.3	1.39	1.03	6.4	2.77	1.84
RG	4.66	43	30	27	Cl	7.02	1.77	0.18	83.9	19.7	1.65	1.19	5.37	1.91	1.06
WM	4.49	50	33	17	Cl	9.68	1.78	0.22	60	17.1	3.56	2.76	3.32	0.91	1.07

HARC-Holeta Agricultural Research Center, RG-Robgebeya, WM-Watabacha Minjaro, Avail P-Available Phosphorus, OC-Organic Carbon, TN-Total Nitrogen, CEC- Cation Exchange Capacity, Ac-Exchangeable Acidity, exAl-exchangeable Al, Cl-Clay.

Selected soil chemical properties after harvesting

The results of soil analysis after crop harvest are depicted in Table 3 and 4. The interaction effect of lime by P fertilizer was significant ($P \leq 0.05$) on some selected soil chemical properties such as exchangeable Al (exAl) at HARC and Robgebeya; and Ac at Robgebeya after harvesting of malt barley. Most of the studied soil parameters were significantly different for applied lime. Effect of independent factor, lime was significant on soil available phosphorus at HARC. Similarly, the effect of lime on soils of all sites were responsive to applied lime in terms of pH, Ac and exAl after harvesting. Response to soil avail P to applied P fertilizer was highly significant ($p \leq 0.05$) at all sites and on Ac at Watabacha Minjaro (Table 4).

Application of P fertilizer at the rates of 33 kg ha^{-1} resulted in the highest significant ($p \leq 0.05$) result of soil avail. P after harvesting at HARC, Robgebeya and Watabacha Minjaro. Statistically significant ($p \leq 0.05$) soil pH, Ac and exAl were recorded for plots treated with lime at the rate of 4.68 t ha^{-1} at all sites after harvesting except from 3.9 t ha^{-1} lime at Watabacha Minjaro. Similarly, the exAl recorded was comparable with lime applied at the rates of 3.12 and 3.9 at Robgebeya (Table 4). Soil reaction increased with increased application of lime whereas the exchangeable acidity and aluminum deceased. This indicates that applied lime has neutralized the acidity and increased pH, lowered the exchangeable acidity and Al. Getachew *et al.* (2017) indicated that amelioration of soil acidity with lime amendment which facilitates detoxification of Al and Mn activity. Detoxification of Al can be achieved by increasing soil pH which in turn certainly results in decrease of Al solubility thereby minimizes its toxic effect on plants. Nduwumuremyi *et al.* (2014) indicated that plant growth improvement in acid soils is not only due to addition of basic cations (Ca, Mg), but also due to increase in pH that reduces toxicity of phytotoxic levels of Al. Peter (2017) also reported that application of lime significantly reduced the exchangeable acidity compared to plots that were not treated by lime.

In this study the pH of the soils improved after application of lime from initial 4.83, 4.86 and 4.58 to 5.52, 5.53 and 5.13 at HARC, RG and WM respectively. Application of lime highly decreased Ac and exAl as the level of applied lime rates increased. The Ac decreased from initial 1.61, 1.62 and 3.73 to 0.28, 0.23 and 0.79 $Cmol_{(+)}kg^{-1}$ soil at HARC, RG and WM respectively; similarly, the exAl decreased from initial 1.13, 1.09 and 3.02 to 0.12, 0.07 and 0.18 $Cmol_{(+)}kg^{-1}$ soil at HARC, RG and WM respectively. The exAl in all lime applied plots decreased below 1.0 $cmol_{(+)}$ kg^{-1} soil. This happened at Robgebeya where the lime rate was greater than 3.9 t ha^{-1}. This has contributed to better improvement in soil properties. Similar result was reported from the study on Kenyan soil by Mohammed *et al.* (2016).

Growth and yield Attributes

Plant height and days to physiological maturity

The mean square tables for the studied parameters of malt barley are indicated in Table 5. Interaction of lime by P fertilizer didn't bring significant ($p \leq 0.05$) effect, but the main effect lime affected plant height of malt barley significantly ($p \leq 0.05$) at HARC and Watabacha Minjaro. Applied P fertilizer independently affected plant height of malt barley at HARC and Watabacha Minjaro (Table 5). The trend of plant height response to lime was increasing up to 4.68 t ha^{-1} for malt barley at Watabacha Minjaro. Similarly, application of P fertilizer at the rate of 16.5 kg ha^{-1} resulted in the tallest and significant ($p \leq 0.05$) plant height at HARC and Watabacha Minjaro compared to the highest P rates (Table 6)

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Table 3. Mean square result for chemical properties as affected by lime and phosphorus fertilizer application

Source	HARC				Robgebeya				-Watabacha Minjaro			
	avil. P (ppm)	pH(H_2O) (1:2.5)	Ac cmol$_{(+)}$kg^{-1}soil	exAl	avil P (ppm)	pH(H_2O) (1:2.5)	Ac cmol$_{(+)}$kg^{-1}soil	exAl	avil P (ppm)	pH(H_2O) (1:2.5)	Ac cmol$_{(+)}$kg^{-1}soil	exAl
LR	6.42^{*}	0.57^{***}	2.14^{***}	1.1^{***}	16.0^{***}	0.47^{***}	2.39^{***}	1.34^{***}	7.68^{ns}	0.37^{***}	11.3^{***}	10.1^{***}
PR	27.4^{***}	0.03^{ns}	0.10^{ns}	0.01^{ns}	77.9^{***}	0.09^{ns}	0.04^{ns}	0.02^{ns}	70.6^{***}	0.03^{ns}	0.61^{*}	0.001^{ns}
LR*PR	0.65^{ns}	0.04^{ns}	0.06^{ns}	0.09^{*}	6.35^{ns}	0.05^{ns}	0.11^{**}	0.07^{**}	4.94^{ns}	0.01^{ns}	0.16^{ns}	0.11^{ns}
EMS	1.89	0.10	0.069	0.31	3.91	0.04	0.038	0.025	5.15	0.018	0.171	0.055
Mean	7.85	5.18	0.89	0.62	12.2	5.27	0.64	0.38	12.44	4.89	2.17	1.47

HARC-Holeta Agricultural Research Center, LR-Lime Rate, PR-Phosphorus Rate, EMS- error mean square, avil P-Available Phosphorus, Ac-Exchangeable Acidity, exAl-exchangeable Al.

Table 4. Some selected soil chemical properties as affected by lime and phosphorus fertilizer application after harvest

LR (t ha^{-1})	HARC				Robgebeya				Watabacha Minjaro			
	AP (ppm)	pH-H_2O (1:2.5)	Ac cmol$_{(+)}$kg^{-1}soil	exAl	AP (ppm)	pH-H_2O (1:2.5)	Ac cmol$_{(+)}$kg^{-1}soil	exAl	AP (ppm)	pH-H_2O (1:2.5)	AC cmol$_{(+)}$kg^{-1}soil	exAl
0	6.32^{b}	4.83^{d}	1.61^{a}	1.13^{a}	6.86^{d}	4.86^{d}	1.62^{a}	1.09^{a}	11.4	4.58^{d}	3.73^{a}	3.02^{a}
1.56	7.72^{a}	4.96^{cd}	1.30^{b}	0.84^{b}	7.31^{cd}	5.23^{c}	0.74^{b}	0.52^{b}	11.7	4.78^{c}	3.02^{b}	2.30^{b}
2.34	7.93^{a}	5.20^{bc}	0.88^{c}	0.67^{c}	7.71^{bc}	5.26^{c}	0.51^{c}	0.27^{c}	12.6	4.86^{bc}	2.36^{c}	1.60^{c}
3.12	7.93^{a}	5.21^{bc}	0.75^{d}	0.58^{c}	9.20^{a}	5.30^{bc}	0.43^{cd}	0.22^{cd}	13.2	4.93^{b}	2.02^{c}	1.15^{d}
3.9	8.66^{a}	5.34^{ab}	0.55^{d}	0.40^{d}	9.11^{a}	5.47^{ab}	0.28^{de}	0.10^{d}	13.8	5.13^{a}	1.10^{d}	0.61^{e}
4.68	8.60^{a}	5.52^{a}	0.28^{e}	0.12^{e}	8.18^{b}	5.53^{a}	0.23^{e}	0.07^{d}	11.9	5.09^{a}	0.79^{d}	0.18^{f}
Lsd (0.05)	1.31	0.3	0.25	0.17	0.67	0.2	0.19	0.15	ns	0.13	0.4	0.22
PR (kg ha^{-1})												
0	6.65^{c}	5.23	0.97	0.6	6.93^{c}	5.21	0.63	0.38	10.28^{c}	4.85	2.38^{a}	1.47
16.5	7.79^{b}	5.14	0.9	0.64	8.20^{b}	5.35	0.6	0.35	12.01^{b}	4.93	2.06^{b}	1.48
33	9.12^{a}	5.16	0.82	0.62	9.06^{a}	5.26	0.68	0.4	14.42^{a}	4.9	2.07^{b}	1.48
Lsd (0.05)	0.94	ns	ns	ns	0.48	ns	ns	Ns	1.34	ns	0.28	ns

Means with the same letter in the same column for each dependent factor are not significantly ($p \leq 0.05$) different from each other. HARC-Holeta Agricultural Research Center, LR-Lime Rate, PR-Phosphorus Rate, AP -Available Phosphorus, Ac-Exchangeable Acidity, exAl-exchangeable Al, ns- non significant.

Table 5. Mean square results for malt barley growth and yield parameters as affected by lime and phosphorus fertilizer

Sites	Variation	PH (cm)	DTPM	Sl (cm)	NSPS	GY (t ha^{-1})	BY (t ha^{-1})	HI
HARC	LR	12.3^{ns}	11.9^{ns}	0.69***	3.67***	3140.4***	3787.7**	4.32***
	PR	67.9***	426.2***	2.23***	23.6***	6476.0***	24325.5***	1.14*
	LR*PR	10.7^{ns}	12.9*	0.09^{ns}	0.54^{ns}	166.8*	1044.7^{ns}	0.16^{ns}
	EMS	5.54	5.81	0.13	0.66	73.8	633.0	0.22
RG	LR	211.6^{ns}	4.5^{ns}	0.22^{ns}	4.39*	1212.1***	3116.7***	0.78***
	PR	582.5^{ns}	163.7***	3.29***	1.28^{ns}	8118.3***	13388.4***	6.84***
	LR*PR	245.7^{ns}	2.1^{ns}	0.11^{ns}	1.81^{ns}	210.2**	140.6^{ns}	0.29*
	EMS	209	2.9	0.13	3.03	60.6	399.6	0.11
WM	LR	112.6***	131.3***	0.22***	18.5***	6701***	22957.5***	1.96***
	PR	75.1***	457.2***	2.55***	61.1***	1408.4***	15618.4***	7.55***
	LR*PR	3.9^{ns}	11.6^{ns}	0.03^{ns}	1.27^{ns}	1935.1**	1552.0*	0.33*
	EMS	10.7	21.6	0.10	3.10	119.3	595.9	0.13

HARC-Holeta Agricultural Research Center, RG-Robgebeya, WM-Watabacha Minjaro, LR-lime Rate, PR-Phosphorus Rate, EMS-error mean square, PH-plant height, DTPM-days to physiological maturity SL-spike length, NSPS-number of spiklets per spike, GY-Grain Yield, BY-Biomass Yield, HI- Harvest Index.

The interaction effect of lime by P fertilizer showed significant ($p \leq 0.05$) difference on days to physiological maturity (DTPM) at HARC (Table 5). Combined application of lime (t ha^{-1}) by P fertilizer (kg ha^{-1}) at the rates of 3.12/33 and 3.9/33 at HARC resulted in significantly ($p \leq 0.05$) higher DTPM than the control treatment (Table 7).

The main factor, lime showed significant ($p \leq 0.05$) difference on DTPM for malt barley at Watabacha Minjaro site. Similarly, P fertilizer application affected DTPM of malt barley at Robgebeya and Watabacha Minjaro. The shortest DTPM of malt barley at Watabacha Minjaro was recorded from plots treated with lime at the rate of 1.56 t ha^{-1}. The applied P fertilizer gave the shortest DTPM for malt barley with 16.5 at Robgebeya and Watabacha Minjaro (Table 6). Application of the inputs have greatly contributed for the improvement of malt barley growth parameters such as PH and DTPM. These growth parameters benefited either from combined application of lime and P or independent applications of the inputs compared to the control. Similar results reported by Getahun and Bobe (2016) that lime and P fertilizer application contributed to wheat growth parameters.

Spike length, number of spikelets per spike

The interaction of lime by P fertilizer did not affect the spike length, but the main factors lime and P fertilizer significantly ($p \leq 0.05$) affected the spike length of malt barley (Table 5). The tallest spike length was recorded at HARC and Watabacha Minjaro from applied lime at the rates of 3.9 and 4.68 t ha^{-1}, respectively. Nevertheless, the recorded results were statistically different only from plots that received no lime and 1.56 t ha^{-1} lime at HARC and control plot at Watabacha Minjaro site. The tallest significant ($p \leq 0.05$) and superior response of spike length of malt barley to applied P fertilizer at the rate 33 kg ha^{-1} was recorded at HARC and Watabacha Minjaro (Table 6).

The response of number of spikelets per spike (NSPS) to combined application of lime and P fertilizer was not statistically significant ($p \leq 0.05$) at all sites. Independent use of lime and P fertilizer affected NSPS of malt barley (Table 5). The highest significant ($p \leq 0.05$) NSPS of malt barley was recorded from lime application at the rate of 2.34, 4.68 and 3.12 t ha^{-1} at HARC, Robgebeya and Watabacha Minjaro, respectively. The results were not statistically different from treatments that received highest lime amount. The highest NSPS of malt barley were counted from plots that received P fertilizer at the rate of 33 kg ha^{-1} at HARC and Watabacha Minjaro sites (Table 6). Better SL and NSPS attained from treatments with lime and P application, this might happen as detrimental soil acidity problem solved because of application of lime and the plants can utilize the inherent soil and applied P.

The main factors; lime and P fertilizer applied have greatly contributed for the improvement of malt barley growth parameters such as SL and NSPS. Most of these parameters were responsive to either combined application of lime and P or independent applications of the inputs compared to the control. Similar reported by Mekonnen *et al*. (2014) that combined use of lime and P fertilizer increased the spike length and number of spikelets per spike.

Table 6. Yield and some growth parameters as affected by main effects of applied lime and Phosphorus

	BY		HI	Pant Height (cm)			DTPM		Spike length (cm)			NSPS		
LR (t ha-1)	HARC	RG	HARC	HARC	RG	WM	RG	WM	HARC	RG	WM	HARC	RG	WM
0	6.83^{c}	5.24^{b}	25.3^{d}	91.2	68	77.5^{b}	132	147.3^{a}	7.4^{c}	8.01	8.1^{b}	25.4^{b}	28.4^{bc}	22.9^{b}
1.56	7.42^{bc}	5.41^{b}	32.4^{c}	93.8	70	83.3^{b}	131	138.8^{b}	7.6^{bc}	8.09	8.3^{ab}	25.7^{b}	27.8^{c}	26.1^{a}
2.34	8.47^{a}	5.43^{b}	30.2^{c}	93.9	67	85.4^{ab}	131	136.9^{b}	7.9^{ab}	8.19	8.5^{a}	26.7^{a}	28.7^{ac}	26.2^{a}
3.12	8.41^{a}	6.08^{a}	38.2^{b}	94.5	68	85.3^{ab}	132	139.3^{b}	8.0^{ab}	8.44	8.4^{ab}	26.7^{a}	29.0^{abc}	26.9^{a}
3.9	7.83^{ab}	6.50^{a}	39.2^{b}	94	80	85.8^{ab}	130	138.0^{b}	8.1^{a}	8.32	8.4^{ab}	26.6^{a}	29.6^{ab}	26.6^{a}
4.68	7.3^{bc}	6.56^{a}	44.4^{a}	93.2	67	87.6^{a}	132	138.0^{b}	8.0^{a}	8.19	8.6^{a}	26.9^{a}	30.4^{a}	25.6^{a}
Lsd (0.05)	0.76	0.61	4.45	ns	ns	3.1	ns	4.4	0.3	ns	0.29	0.8	1.7	1.7
PR (kg ha-1)														
0	6.42^{c}	4.98^{c}	32.0^{b}	91.3^{b}	64	81.8^{b}	135^{a}	145.3^{a}	7.5^{b}	7.56^{c}	8.0^{c}	25.2^{c}	28.8	23.7^{b}
16.5	8.04^{b}	5.93^{b}	36.3^{a}	93.8^{a}	76	85.3^{a}	130^{b}	138.4^{b}	7.7^{b}	8.35^{b}	8.4^{b}	26.3^{b}	28.9	26.2^{b}
33	8.67^{a}	6.70^{a}	36.5^{a}	95.2^{a}	70	85.3^{a}	129^{b}	135.4^{b}	8.2^{a}	8.81^{a}	8.8^{a}	27.5^{a}	29.3	27.3^{a}
Lsd (0.05)	0.539	0.43	3.15	1.6	ns	2.2	1.1	3.1	0.2	0.33	0.21	0.6	ns	1.2
CV	10.3	10.1	13.3	2.5	21	3.9	1.3	3.3	4.6	6	3.7	3.1	6	6.8
Mean	7.71	5.87	34.9	93.4	70	81.8	131	145.3	7.8	8.24	8.4	26.3	29	25.7

Means with the same letter in the same column for each dependent factor are not statistically significant ($p \leq 0.05$). LR- lime Rate, PR-phosphorus Rate, BY- biomass yield, HI-harvest index, DTPM- days to physiological maturity, HARC-Holeta Agricultural Research Center, RG-Robgebeya, WM-Watabacha Minjaro, CV- coefficient of Lsd-least significant difference, ns- non significant.

Grain, biomass yield and harvest index

Grain yields of malt barley were significantly ($p \leq 0.05$) affected by the interaction of lime by P fertilizer at all sites (Table 5). The highest significant GY of malt barley was recorded from combined application of lime (t ha^{-1}) by P fertilizer (kg ha^{-1}) at the rate of 3.12/16.5 at HARC and Watabacha Minjaro and 3.12/33 at Robgebeya. This is better compared to higher amount of lime by P fertilizer applied statistically (Table 7).

Table 7. Yield and yield component of malt barley as affected by interaction effects of applied lime and Phosphorus

LR	PR	Grain yield (t ha^{-1})			BY	DTPM	HI	
		HARC	RG	WM	WM	HARC	RG	WM
0	0	1.51^{i}	1.47^{g}	1.33^{h}	5.26^{h}	127.7^{a}	33.3^{d}	25.4^{h}
	16.5	1.66^{hi}	1.85^{fg}	1.91^{fg}	6.30^{gh}	119.3^{def}	35.7^{d}	30.3^{fgh}
	33	1.99^{gh}	2.16^{ef}	1.94^{fg}	6.74^{fg}	116.3^{fgh}	35.3^{d}	29.3^{gh}
1.56	0	1.73^{hi}	1.52^{g}	1.65^{gh}	6.12^{gh}	121.3^{de}	33.3^{d}	26.9^{h}
	16.5	2.57^{def}	2.44^{df}	3.36^{e}	9.52^{cd}	115.7^{fgh}	44.5^{abc}	35.2^{efg}
	33	2.89^{cd}	2.61^{cd}	3.64^{d}	9.94^{bc}	118.0^{efg}	42.4^{c}	36.7^{cdef}
2.34	0	1.97^{ghi}	1.59^{g}	2.25^{f}	7.79^{ef}	122.3^{cd}	33.8^{d}	29.0^{gh}
	16.5	2.77^{de}	2.81^{cd}	3.33^{e}	8.34^{bc}	115.7^{fgh}	49.6^{a}	40.3^{bcde}
	33	2.96^{cd}	2.55^{cde}	4.04^{cd}	9.41^{cd}	118.0^{fgh}	43.3^{bc}	42.9^{abc}
3.12	0	2.26^{fg}	1.64^{g}	2.40^{f}	9.08^{cde}	123.0^{bcd}	31.5^{d}	26.7^{h}
	16.5	3.67^{ab}	2.90^{c}	4.33^{abc}	9.57^{cd}	116.3^{fgh}	47.4^{abc}	45.3^{ab}
	33	3.82^{a}	3.35^{ab}	4.63^{ab}	9.88^{bc}	114.0^{h}	48.7^{ab}	47.0^{a}
3.9	0	2.27^{fg}	1.85^{fg}	2.41^{f}	9.17^{cde}	126.7^{ab}	33.6^{d}	26.2^{h}
	16.5	3.32^{bc}	2.96^{bc}	4.23^{abc}	11.74^{a}	115.3^{gh}	44.8^{abc}	36.7^{cdef}
	33	3.52^{ab}	3.36^{ab}	4.71^{a}	11.14^{ab}	114.0^{h}	45.6^{abc}	42.4^{abcd}
4.68	0	2.35^{efg}	1.87^{fg}	3.45^{e}	9.50^{cd}	126.0^{abc}	34.8^{d}	36.3^{def}
	16.5	3.56^{ab}	2.82^{cd}	4.13^{bcd}	10.04^{bc}	115.7^{fgh}	44.4^{abc}	41.1^{abcde}
	33	3.72^{ab}	3.63^{a}	4.68^{ab}	10.27^{bc}	114.7^{gh}	46.8^{abc}	45.7^{ab}
Lsd (0.05)		0.466	0.408	0.557	1.44	3.94	5.6	6.6
CV		10.1	14.8	10.8	8.7	2	8.2	10.0

Means with the same letter in the same column are not significantly ($p \leq 0.05$) different from each other. HARC-Holeta Agricultural Research Center, RG-Robgebeya, WM-Watabacha Minjaro, LR-lime Rate (t ha^{-1}), PR-Phosphorus Rate (kg ha^{-1}), BY-Biomass Yield, HI- Harvest Index, Lsd-least significant difference, CV- coefficient of variation.

Biomass yields of malt barley at Watabacha Minjaro were significantly affected by interaction of lime by P fertilizer (Table 5). The highest significant ($p \leq 0.05$) BY of malt barley at Watabacha Minjaro was recorded from interaction of lime (t ha^{-1}) by P fertilizer (kg ha^{-1}) at the rate of 3.9/16.5 compared to the lowest combined input used (Table 7). Though the interaction of lime by P fertilizer was not significant ($p \leq 0.05$), there was response for BY of malt barley at HARC and Robgebeya for the applied lime and P fertilizer independently (Table 5). Accordingly, application of lime at the rates of 2.34 and 3.12 t ha^{-1} at HARC and Robgebeya, but were not statistically significant ($p \leq 0.05$) from plots treated with 3.12 and 3.9 t ha^{-1} at HARC and 3.9 and 4.68 at Robgebeya site. Similarly, P fertilizer applied at the rate of 33 kg ha^{-1} yielded the highest BY than the other treatments at HARC and Robgebeya sites. For better biomass yield with lowest input, it would be advantageous to use 3.9/16.5 at Watabacha Minjaro site, independent use of lime (t ha^{-1}) and P fertilizer (kg ha^{-1}) at the rate of 2.34 and 3.12 lime with 33 kg ha^{-1} P fertilizer at HARC and Robgebeya, which is advantageous statistically (Table 6).

Interaction of lime by P fertilizer significantly affected harvest index (HI) of malt barley at Robgebeya and Watabacha Minjaro sites (Table 5). The highest significant ($p \leq 0.05$) HI of malt barley was recorded at Robgebeya and Watabacha Minjaro from interaction of lime (t ha^{-1}) by P fertilizer (kg ha^{-1}) at rates of 2.34/16.5 and 3.12/33, respectively. The recorded results were not statistically different from plots received lime (t ha^{-1}) in combination with P fertilizer (kg ha^{-1}) at the rates of 1.56/16.5, 3.12/16.5, 3.12/33, 3.9/16.5, 3.9/33, 4.68/16.5 and 4.68/33 at Robgebeya site and 2.34/33, 3.12/16.5, 3.9/16.5, 4.68/16.5 and 4.68/33 at Watabacha Minjaro site (Table 7). Though, response of HI not significantly affected by the interaction of lime and P fertilizer there was response for independent use of lime and P fertilizer at HARC for malt barley (Table 5). Lime applied at the rate of 4.68 t ha^{-1} resulted in the highest significant ($p \leq 0.05$) HI of malt barley than the other lime rates at HARC. Similarly, P applied at the rate of 16.5 kg ha^{-1} resulted in the better HI of malt barley than the control (Table 6).

It was observed that keeping P fertilizer at zero and increasing the lime rates resulted in increased yield of malt barley, in similar manner, keeping the lime rats at zero and increasing the P fertilizer increased yield and yield components of malt barley. Plots that did not receive the inputs resulted in the lowest grain and biomass yields (Table 7). Though plots that received the maximum inputs almost gave the highest grain and biomass yields, they were not statistically different from combined application of lime (t ha^{-1}) by P fertilizer (kg ha^{-1}) at the rates of (3.12/16.5) at HARC and Watabacha Minjaro. Similarly; malt barley with (3.12/33) at Robgebeya study site are the best combination compared to other treatment interaction.

These treatments have advantage of grain yield (143, 128 and 225%) at HARC, Robgebeya and Watabacha Minjaro sites, respectively (Table 6 and 7). Inconformity to these Getachew *et al.* (2017) reported barley grain yield advantage of 274% by lime application as compared to unlimed plots on Nitisols of Bedi, central highlands of Ethiopia. Hailu and Getachew (2006) also reported a triple barley grain yield increase by application of 3 t ha^{-1} of lime compared to no lime application at Adadi, Southwest Showa. Shiferaw and Anteneh (2014) also reported highest barley grain yield (2.79 and 3.28 t ha^{-1}) from combined application of NPK at the rate of 46/40/50 kg ha^{-1} and half the recommended lime rate (3.84 and 0.85 t ha^{-1}) at Chencha and Hagerselam, respectively. Furthermore, Farhoodi and Coventry (2008), reported about 30% durum wheat and 70-75% yield increments of wheat, barley and faba beans and a year after lime application. Though, acidic soil condition is a major constraint for barley production at the study sites, this finding indicates possibility to alleviate the problem by application of lime and P fertilizer at appropriate rate on acidic soil.

Lime and P fertilizer application have contributed to increased grain and biomass yields. The possible reason could be application of lime with P fertilizers which might have influence on Al toxicity to increase soil pH and decrease detrimental effect of lower soil pH conditions. Hence improve several chemical and biological changes in the soils and overall nutrient availability which are beneficial or helpful in improving crop yields on acid soils. This indicates that application of lime effectively increased soil pH from extremely acidic to medium and neutral range and finally improved growth performance and grain yield of malt barley. Similar reports by Achalu *et al.* (2012), Nduwumuremyi *et al.* (2014), Peter (2017) and Woubshet *et al.* (2017) indicated that crops responded to combined application of lime and fertilizers in acid soils.

The straw yield increased without affecting the increase in grain yield. This finding was also reported by Woubshet *et al.* (2017). This could benefit the farmers in the highlands of Ethiopia by increasing grain yield and straws in parallel to alleviate both food and feed security problems. The observed increase in dry matter yield with increasing P rate in treatments with no lime application confirmed that P is limiting factor to malt barley growth in acidic soil of the study area. Furthermore, Shiferaw and Anteneh (2014) found that application of lime and all combinations of fertilizers, either alone or combined, significantly increased yield over lime untreated plots. Application of lime by itself could have contribution to increased nutrient P availability through its effect on neutralization of soil acidity and Al^{3+} toxicity, which simultaneously improve crop yields.

This increased yield might be due to increased pH which creates improved nutrients recovery as a result of lime application (Woubshet *et al.*, 2017). Supply of Ca^{2+} from lime and increasing availability of plant nutrient P had contribution to the increments of GY, BY and HI. Similar result was reported by Achalu *et al.*, (2012). Increase in grain yield with application of lime is credited to its favorable effect on soil chemical, physical, and microbial properties. Some authors Farhoodi and Coventry (2008) and Getachew *et al.* (2017) described application of lime at an appropriate rate that brings about several chemical and biological changes in the soil, which is beneficial to improve crop yields in acid soils.

The mean harvest index of malt barley observed in this study was > 35% for plots that were treated with combined application of lime by P fertilizer at Robgebeya and Watabacha Minjaro and those with lime above 2.34 t ha^{-1} and all P fertilizers rates at HARC. This could be because of increase in total biomass together with increase in grain yield as reported by Woubshet *et al.* (2017).

CONCLUSIONS

Application of lime has improved some selected soil chemical properties associated with acidity. The pH of the soils increased, while Ac and exAl decreased with liming. Lime and P fertilizer applied have greatly contributed to the growth of malt barley. From this investigation, it is recommended that, 3.12 t ha^{-1} lime combined with 16.5 kg ha^{-1} P fertilizer are good combination for production of malt barley in Welmera District. Nevertheless, the most feasible combination of the two treatments should be recommended after economic analysis.

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