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Full Length Research Paper

Response of food barley (*Hordeum vulgaer* L.) with combined uses of lime and varied phosphorus sources on acidic nitisols of Wolmera District

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A field experiment was conducted on acidic nitisols of Wolmera District in two locations at 2017 cropping season to determine the response of barley for the combined application of lime and different phosphorus fertilizers. Several barley growth performances, yield, and plant samples were collected with soil samples to determine soil acidity attributes and nutrient use efficiency. Barley grain yield and growth performances were significantly (P<0.05) affected by the application of different phosphorus sources. The highest grain yield was recorded from NPSB phosphorus fertilizer source in both experimental sites followed by partly acidulated rock phosphate (PARP) with yield improvement of 89 and 52%, over the control treatment respectively. Growth parameters like plant height, spike length, number of tillers, etc., and physical grain quality data (hectoliter weight and thousand seed weight) were significantly affected by all phosphorus sources. The combination of phosphorus fertilizer (NPSB at 69 kg P_2O_5 ha^{-1}) with lime got a higher grain yield advantage over other treatments. The highest phosphorus concentration in the plant parts was recorded from the fertilizer source of NPSB. This was due to its immediate availability to the plant uptake compared to other sources. The use of partly acidulated rock phosphate or organic hyper-phosphate (MOHP) fertilizer, as an alternative for NPSB application provides a competitive yield advantage for acidic soils of Wolmera area or other similar soil type and agroecology of the country.

Key words: Acid soil, food barley, lime, partly acidulated rock phosphate (PARP), organic hyper-phosphate (MOHP), NPSB, yield.

INTRODUCTION

Agriculture is a key driver of Ethiopia's economy and it directly supports 85% of the population, contributes about 40% to the gross domestic product (GDP), and 80% to the export value. However, insufficient productivity of the land for an ever-increasing population has resulted in food insecurity. Soil fertility declines and accompanying

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low levels of agricultural production have been voiced to still be among the serious challenges (Ministry of Agriculture and Rural Development MoARD, 2008). These could be attributed to many factors; complete crop residue removal, low rate fertilizer application, soil acidity, and low use of seeds of improved crop varieties.

Barley (*Hordeum vulgare* L) is one of the most dominant cereal crops widely grown by small-scale farmers under rainfed conditions in the highlands of Ethiopia. It ranks third next to teff and wheat in mid-altitude and first in high-altitude areas in terms of area coverage and production (Central Statistics Agency-CSA, 2016), covering 13% of the total area under cereals. Among several major barley production constraints in the central high land region of Ethiopian soil, fertility limitation takes the lions-role. The national average yield of barley is too low, with a mean of about 2.0 t ha^{-1} (CSA, 2016) due to poor soil fertility (Getachewu et al., 2005). This is true particularly for N and P nutrients due to continuous cropping of cereals and the low level of fertilizer usage (Hailu et al., 1991; Amsal et al., 1997).

Soil acidity is one of the major constraints for the production and productivity of crops in high rainfall areas of Ethiopia. According to the Ethiopian soil information system EthioSIS (2014), acidic soil is estimated to be covering more than 43% of the arable land in Ethiopia of which 13% is strongly acidic (pH < 4.5). Despite these high-level statistics, the situation is not well-understood in detail at the local level, or with more up-to-date estimates of severity (IFPRI, 2010). Different human and climatic factors have contributed to soil acidification in Ethiopia including erosion, nutrient and organic matter depletion due to continuous cropping and residue removal along with the presence of high precipitation that leads to basic cation leaching (Mesfin, 1998). The process of acidification results from the replacement of basic cations Ca, Mg and K in the soil exchange sites with Al, Mn and Fe and increased the concentration of H^+ ion in the soil solution. Where soil pH is lower than optimal (5.5 and below), the availability of nutrients needed for growth is reduced.

This condition also usually leads to Al and Mn toxicity plus a deficiency in N, P, K, Mg, Ca and Mo. This has multiple effects for the plant growth and nutrient management as this leads to lack of or reduced response to applied fertilizers due to high P fixation by oxides of Al and nutrient deficiency which can result in 50% and above yield reduction (IFPRI, 2010).

To improve acid soil related production problems, soil and crop management effort has been the main important research and development agenda in the country since 2006 (Soil Sector Strategy). Liming with calcium carbonate ($CaCO_3$) is generally the first management practice that comes to mind when the question of high phosphorus fixation in acid soils is raised (Alemayehu et al., 2017). Thus, lime with P application on acid soils has been among the interventions widely studied on the performance of major crops in different agro-ecologies.

Crop management components along with lime include the use of fertilizer, improved seed and agronomic practices. Above all, long-term experiments also emphasize the need for greater use of fertilizers (mineral and organic) to remedy the nutrient deficiencies in Africa (Bekunda et al., 1997). The work of Shiferaw and Anteneh (2014) have also indicated that half dose of recommended lime application with NPK fertilizer significantly increased barley yield both at Alisols of Chencha and Luvisols of Hagereselam indicating that balanced fertilization of acidic soils is critical for sustainable crop production. For intensive and continuous crop production, these inputs should aim at balanced utilization of nutrients along with the efforts of maintaining the soil pH at an optimal level by liming (FAO, 2000).

In spite of the need for balanced fertilization in acid soil along with lime, only N and P have been applied widely in the form of Urea and DAP (diammonium phosphate) as a high-grade fertilizer in order to obtain optimum harvest in the Wolmera district of Ethiopia. Regardless of the blanket application of these nutrients and unbalanced fertilization of the soil application per hectare in Ethiopia, it has increased five times since the 1980s and is better than the sub-Saharan Africa average (IFPRI, 2010). This indicates the increased demand for inorganic fertilizers uses by Ethiopian farmers to maximize their productivity. Consequently, unbalanced fertilizer use has resulted in widespread multi-nutrient deficiencies in Ethiopian soils (Mesfin, 1998). Thus, lime technology must consider the application of both macro and micro plant nutrients because if any nutrient is deficient, it will affect both crop yield and quality, as well as nutrient use efficiency of other applied plant nutrients.

Very recently, however, this generalized and over-simplistic driven fertilizer recommendation approach has been replaced by balanced fertilizer and site-specific nutrient deficiency-based schemes. The EthioSIS (2014) soil fertility map has provided basic data for balanced fertilization research in major Ethiopian soils. To this effect, different fertilizer blends have been evaluated for their effectiveness in addressing site-specific deficiency and improving nutrient use efficiency and productivity across different agro-ecologies and soil types (Getachew, 2005). In line with this, correcting the nutrient deficiency and imbalance through suitable fertilizer type and nutrient composition is very important in low pH soils in order to improve the lime affordability and adoptability that enables the split application of bulky recommended rate while maintaining the crop performance.

Therefore, the objective of this study was to assess the effects of lime, different phosphorus fertilizer sources and their appropriate combined application rates on growth performance, grain yield and quality of food barley in Wolmera district and similar agro-ecologies.

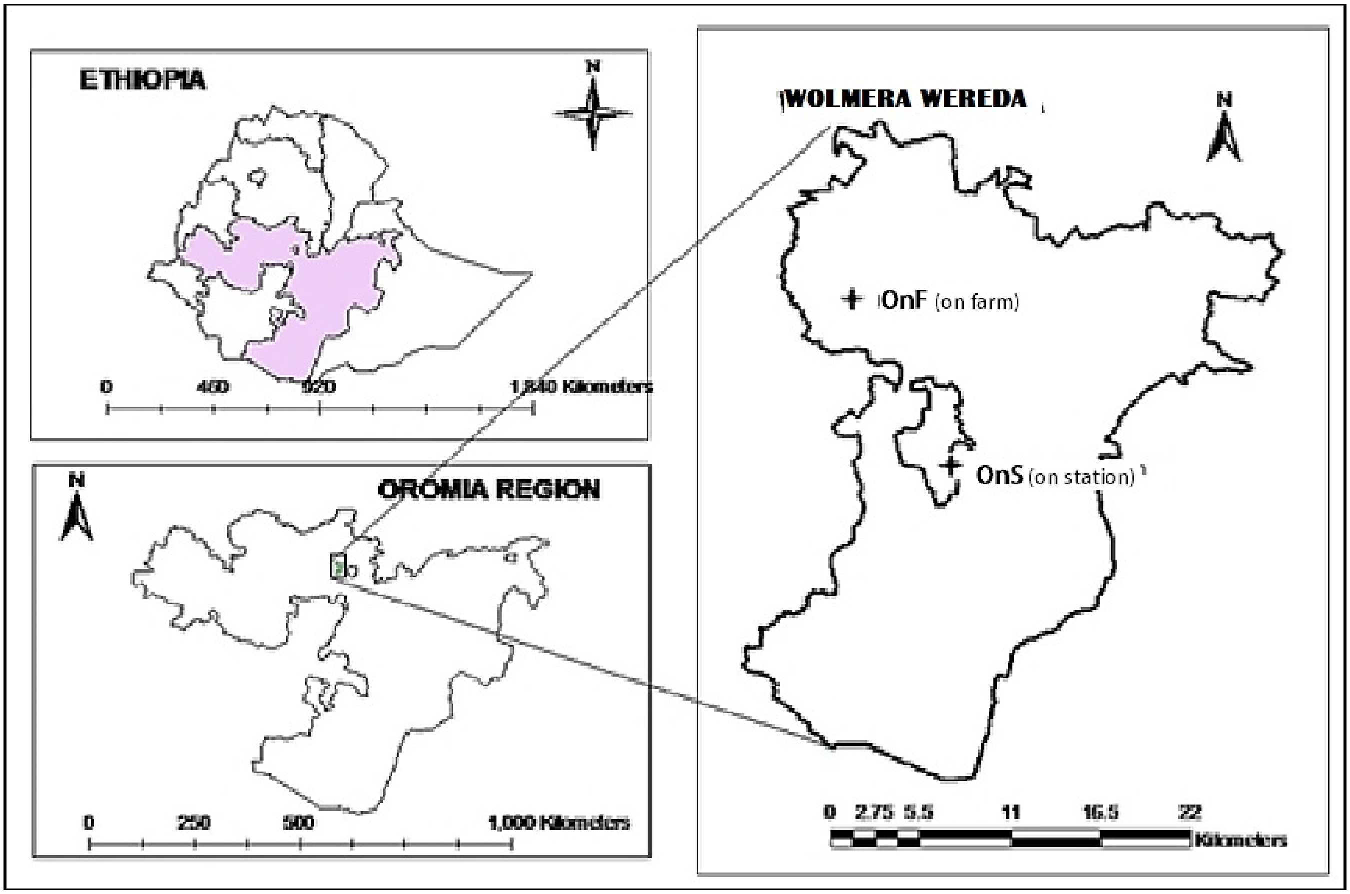

Figure 1. Location of the study area at Holeta Agricultural Research Center or on-station (OnS) and Rob Gebeya kebele on farmer's field or on-farm (OnF) in Wolmera district, Oromia Regional State.

MATERIALS AND METHODS

Description of study area

Field experiment was conducted in Wolmera district at two locations, viz: at Holeta Agricultural Research Center Farm (OnS) and on farmer's field (OnF) at Rob-Gebeya kebele in the central highland of Ethiopia, west of Addis Ababa (Figure 1). The experimental sites were geographically located at DMS (degree minute second) georeferenced coordinate units:

1. On-Station (OnS): at 9^0.03'.15.8" N latitude; 38^0.30'.07.04" E longitude with mean altitude of 2365 masl
2. On-Farm (OnF): at 9^0.08'.24.7" N latitude; 38^0.26'.07." E longitude with altitude 2625 masl.

Wolmera District is one of major barley producer districts in the Oromia Regional State of central Ethiopian highland, which is part of the Oromia Special Zone Surrounding Finfinne (Addis Ababa). It is bordered to the south by Sebeta Hawas, to the west by West Shewa Zone, on the north by Mulo district, to the northeast by the Sululta city and on the East by the city of Addis Ababa.

From the recent five years (2013-2017 inclusive) weather records for Holeta Agricultural Research Center, it was observed that a mean annual air temperature of 14.6°C that varies from 5.8°C minimum monthly average up to 23.4°C monthly mean maximum temperature. The absolute monthly mean maximum of 28.8°C and minimum of -0.6°C occurred in January and March 2013 respectively. The average sunshine hours are 6.8 h/day in a year and this varies between 2.7 h/day in July and 9.1 h/day in November. Holeta area receives an average total rainfall of 919.4 mm annually, whereas in the study year (2017), 1071.6 mm rain was registered (Figure 2). This is spread over all months except December and ranges from the lowest of 0 mm in December to the highest of 311 mm in August 2017.

Barley (*H. vulgare* L.) was used as test crop for this study, which is one of the most important cereal crops widely grown by small-scale farmers under rain fed conditions in most highlands of Ethiopia. It has suffered from soil acidity more than other major cereals dominantly grown in the study area. Food barley (*H. vulgare* L.) variety BH -1307, which is the most widely acceptable variety in Wolmera areas with a yielding potential ranging from 3000-5000 kg ha^{-1} requires an average number of 137 days to mature with 81 days of heading under ideal environmental condition for production (Bayeh and Stefania, 2006).

Experimental design and treatments

The experiment was conducted using randomized complete block design (RCBD) in factorial arrangement. Four different types of phosphorus fertilizer sources: partly acidulated rock phosphate (PARP), Organic hyper-phosphate (MOHP), NPSB blended fertilizer (formula II) and NAFAKA+ represented by (P1, P2, P3 and P4

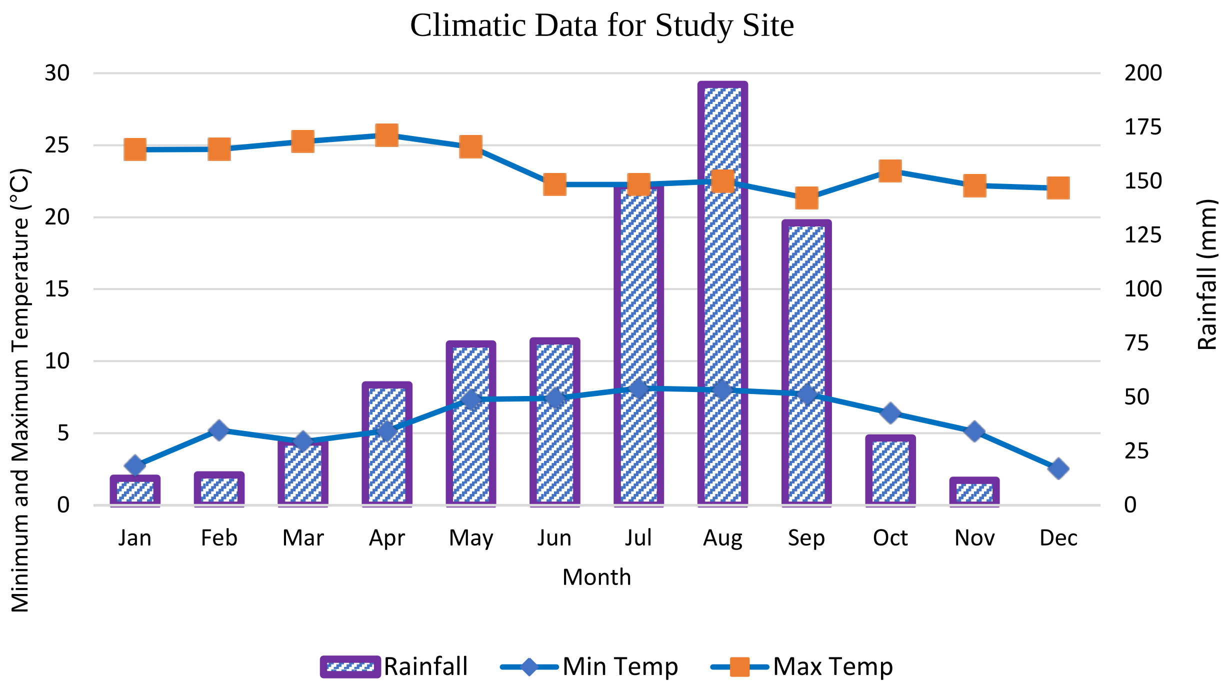

Figure 2. Five years mean climatic data for Holeta Agricultural Research Center taken from center weather station (2013-2017). Major axis at the left side was used for max and min temperature while the minor axis at the right side was used for Rainfall.

Table 1. Chemical composition of different phosphorus sources used for the study.

No.	Phosphorus source	Symbol	Chemical composition (%)							
			N	P_2O_5	K_2O	S	B	Zn	CaO	MgO
1	Partly acidulated rock phosphate	PARP (P1)	-	49	-	7	0.6	2	-	-
2	Organic hyper-phosphate	MOHP (P2)	-	28	-	-	-	-	36	-
3	Formula II	NPSB (P3)	18.1	36.1	-	6.7	0.71	-	-	-
4	NAFAKA plus	P4	9	16	16	5	0.1	0.5	25	2

respectively). Phosphorus fertilizer rates (PR1 half recommended P rate 34.5 P_2O_5 kg ha^{-1} and PR2 fully recommended P rate 69 kg P_2O_5 ha^{-1}) and lime rates (0 lime and 1/4th of LR computed from EA soil exchangeable acidity result for each experimental site) are used with three replications (Table 1). As a control treatment, no input application was used for comparison purposes. Reduced lime rate 1/4th from the required was used since most of P sources have their own incorporated lime. Likewise, liming effects of some P sources which have incorporated CaO/$CaCO_3$ (Table 1) were taken. Different sources of P-fertilizers used are listed below with their chemical composition from P1 up to P4.

In all treatments, major essential nutrients were kept at the same rate except phosphorus (P_2O_5) by using independent sources which does not exist from single granule of phosphorus fertilizer sources (Table 2). Nitrogen, potassium, sulfur and boron are kept at the same rate for all treatments by using fertilizer sources like: Urea CO $(NH_2)_2$ 46% N, Muriate of potash (MOP) KCl 60% K_2O, Ammonium sulphate $(NH_4)_2SO_4$ 21% N and 24% S and Borax ($Na_2B_4O_7.10H_2O$) 11% boron respectively used as other sources of essential nutrients to reduce the confound effects from other nutrients than phosphorus between treatments.

Recommended fertilizer rate for barley production in Wolmera area from the previous study were 69 and 60 kg ha^{-1}, P_2O_5 and N respectively (Bayeh and Stefania, 2006). Depending on EthioSIS soil fertility map (2014), deficient plant nutrient type and recommended fertilizer formulation were determined as NPSB (Figure 3). The application rate of S and B fertilizer was fixed according to the recommended rate of NPSB (Formula II) based on P_2O_5 content. Zn is eliminated since it was not found to be limiting nutrient in both experimental sites as soil fertility map of the Woreda and preliminary soil test results confirmed.

EthioSIS (2014) soil fertility map determines that the blended fertilizer rate combination for Wolmera district specific study site was computed from a combination of NPSB with 69 kg P_2O_5 ha^{-1}. This was computed from blended fertilizer formula II /NPSB at 191 kg ha^{-1} (114 g $plot^{-1}$) application combined with 55 kg ha^{-1} (33 g $plot^{-1}$) urea (Table 3). From total application rate of 191 kg ha^{-1} NPSB fertilizer, we have nutrient contents (P_2O_5= 69 kg ha^{-1}; S=12.4 kg ha^{-1}; B= 1.4 kg ha^{-1}). Thus, other phosphorus fertilizers rate was fixed with these nutrients rate and applied at once while planting is done with band application method, except for urea which is applied in two splits.

Table 2. Treatments description for the effects of lime and different P-source on food barley at Wolmera district.

Experimental factors	Description
Factor 1	- P1= PAPR* - P2= MOHP* - P3= NPSB (Formula II) * - P4= NAFAKA Blend plus*
Factor 2	- PR1= Half dose of recommended P- fertilizer rate (34.5 kg ha^{-1} P_2O_5). - PR2 = Full dose of recommended P - fertilizer rate (69 kg ha^{-1} P_2O_5).
Factor 3	- LM1= Without lime application. - LM2= With lime applied depending on soil initial EA result.

*All required N, K, S and B were added to all P treated plots to avoid the partial treatment effect of some P sources; Zn was not considered since they are found with sufficient level EthioSIS (2014); EA is exchangeable acidity.

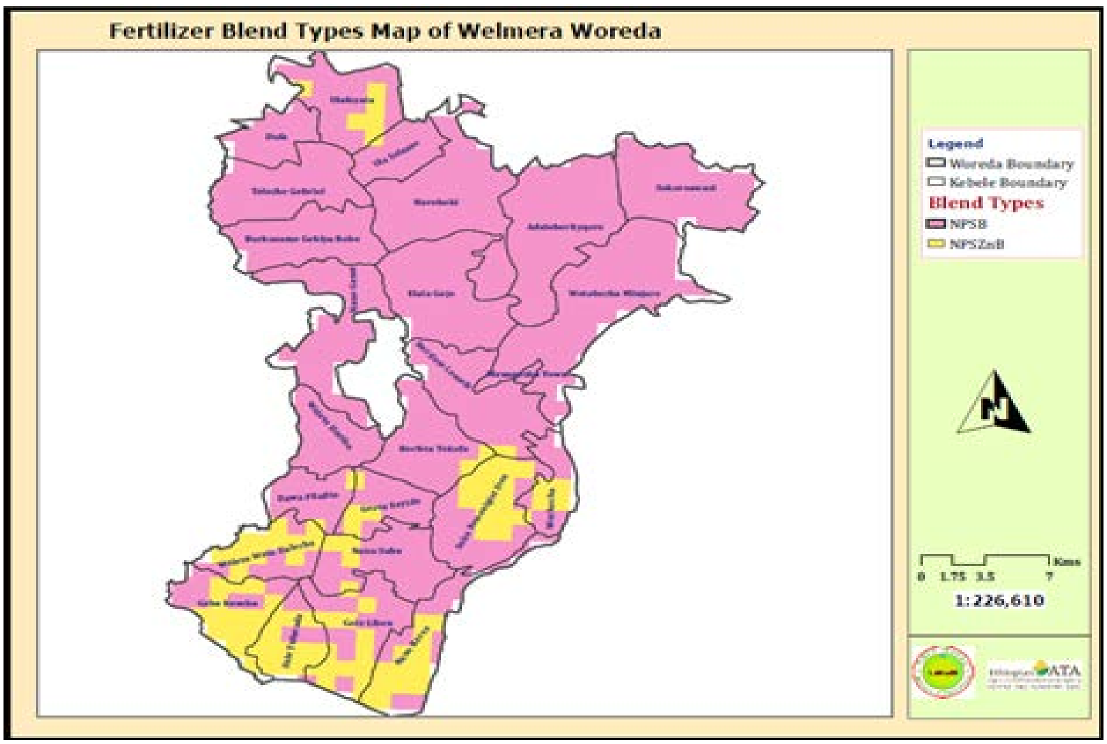

Figure 3. Ethiopian soil information system digital soil fertility map of Wolmera Woreda and its Kebeles in detail with their recommended fertilizer type.
Source: EthioSIS (2014).

Lime requirement (LR) rate determination

The amount of lime required to reclaim each study area acidic soil was determined by using exchangeable acidity method (Kamprath, 1984).

$$LR, CaCO_3 (kg/ha) = \frac{[cmol\ (EA/kg)\ of\ soil \times 0.15\ m \times 10000\ m^2 \times B.D\ (g/cm^3) \times 1000]}{2000} \times Factor \quad (1)$$

Where 0.15 m is the plow depth; 10^4 m^2 is area for 1 ha of land; B.D is bulk density of the soil multiplied by 1000 to convert g cm^{-3} to kg m^{-3}.

The required lime computed for on-station and on-farm experimental sites were 733.5 and 1127 kg ha^{-1} $CaCO_3$ respectively; thereafter 1.5×LR was used as multiplying factor for cereal crops, which eventually results to 1100 and 1691 kg ha^{-1}. For this experiment, 1/4th of LR was used, making the final amount of lime which was

Table 3. Application rate of different P source of fertilizer and other essential nutrients for each treatment.

Treatment No.	P sources (kg ha^{-1})				Other nutrient sources (kg ha^{-1})			
	PARP	MOHP	NPSB	NAFKA+	*N from $CO(NH_2)_2$*	*S from $(NH_4)_2SO_4$*	*B from Borax*	*K from KCl*
1	-	-	-	-	-	-	-	-
2	70.4	-	-	-	115.4	31.1	8.89	43.2
3	140.8	-	-	-	126.3	8.92	5.05	43.2
4	-	123.2	-	-	106.7	51.7	12.7	43.2
5	-	246.4	-	-	106.7	51.7	12.7	43.2
6	-	-	95.5	-	93	-	-	21.5
7	-	-	191	-	55	-	-	43.2
8	-	-	-	215.5	88.3	-	-	-
9	-	-	-	431	45.6	-	-	-

Control treatment was included for different comparisons, that is, Treatment #1. All rates are given as a total bulk weight of each fertilizer source 3.

applied for those experimental sites to be 275.1 and 422.9 kg ha^{-1}, respectively. This reduced amount of lime rate is due to split application of lime where full dose of required lime is applied in four successive years which is widely practiced by small scale barley producer in the study areas. Consequently, for single cropping season, we used full dose of lime requirement rate, showing effects for at least five consecutive years, hence it needs to be reduced to this amount in addition to liming effects of some phosphatic fertilizer used for these study. It was applied 3 weeks before planting using quick lime (CaO) as a liming material which has 179 calcium carbonate equivalence (CCE). Therefore, lime requirement (LR) from $CaCO_3$ source is multiplied by 0.559 to find the CaO amount required for final application rate.

All fertilizer treatments were applied with band application method at planting except nitrogen sources (urea) which is applied into two splits first at planting and the 2nd at tillering growth stage of the barley crop. Planting was done on July 7th and July 12th, 2017 for OnS and OnF trials respectively using row planting with spacing of 20 cm between rows on plot size of 2 m × 3 m., The two border sides were rejected in each experimental plot and the inner 13 rows were taken for all kinds of agronomic data collected from the plants. The seed rate used was 100 kg ha^{-1} (for both experiment sites). Spacing between treatments and replications were kept at 0.5 m and 1 m respectively. The testing site was geo-referenced to generate area specific micro nutrient deficiency information and to produce the micro nutrient blends.

Weed control is done by hand, with weeding frequency of two times for each experimental site. While the first weeding was done at tillering plant growth stage, the 2nd weeding was done before booting growth stage of the barley crop. Several types and intensity of diseases were found to occur during the growing season with the majorly identified ones including: Scaled (*Rhinchosporium secalis*), Net Bloch (*Pyreno phorateres*) and leaf rust (*Puccinia hordei*) diseases observed specially in on-station experimental site. All disease incidence, severity and plant reaction data to the occurred disease was recorded for each experimental unit.

Data collected

Crop phenology and growth parameters

Agronomic data like plant height, spike length, number of spikelets per spike, number of effective and total tiller were collected about the experimental crop like date of flowering (at >75% of plant population flowering in each experimental plot), date of maturity, average plant height (PH) from sample plants, mean spike length, mean number of spikelets per spike, number of total tiller and effective tillers per plant, as well as total biomass at harvesting was collected from all experimental units.

Plant height: This was taken when crop attain maximum height at crop maturity growth stage. Data was taken from 10 random experimental sample plants. It measured from the ground level up to higher tip of the plant by using height meter and the mean results were presented in centimeter measurement unit.

Total number of tiller per plant: During random harvesting, selected sample plants were uprooted and the number of tillers which was raised from single plants were counted, whether productive or not and the average values were taken for each plot. Number of effective tiller per plant is the same as total number of tiller per plant except that it considers only tillers which set grain or with effective spike.

Spike length and number of spikelet per spike: This was taken as the average spike length value measured from ten random sample plants at maturity which were taken for all agronomic data measurement and it is measured in centimeter unit. Similarly, ten spike samples were taken from the sample plants at harvesting, the number of seeds in each spike was counted, and the average number of spikelets was taken as representative data for each experimental plot.

Date of flowering/booting and maturity: Data was taken when more than 75% of plant population was flowers set in each experimental plot. It used to identify each treatment and how to respond to different inputs by comparing with standard number of days required by specific variety of barley and to compare treatments responses on delayed or forced maturity depending on the input variability. Maturity date was taken as the required number of days to attain plant physiological maturity stage of more than 75% of plant population in each experimental plot.

Yield and its components

Dry above ground biomass AGB and grain yield GY were collected from each experimental unit independently for each experimental unit.

Above ground dry biomass (AGB): This was collected using sack in plot base at harvesting. It was taken from middle experimental rows of barley as fresh total biomass. After drying at thrashing time, it was taken as dry above ground biomass yield for all experimental plots.

Grain yield (GY): After threshing the harvested crop, grain yield obtained from each experimental plot were taken by sac and weighted with their moisture percentage using digital balance and moisture tester. Finally, the grain yield was converted into kg ha^{-1} by adjusting to 12% gain moisture level.

Grain physical quality data like thousand seed weight and hectoliter weight was taken beside grain nutrient analysis. Hectoliter Weight (HLW)**/**Test weight, also known as hectoliter mass, is a measure of the volume of grain per unit. It is usually expressed as kg per hectoliter and is a good indication of grain-soundness. Millers usually use test weight as an indication of expected flour yield. It was done by taking 1 kg clean seed sample, grain samples were inserted into the measuring device and results read.

Thousand seed weight (TSW): This was measured by using seed counter and TSW measuring device. Collected grain sample from each experimental plot was determined for their TSW result found from the measuring device.

Grain moisture percentage (MST): This was collected for grain yield weight adjustment measured using HLW meter.

Plant and soil sample collection, preparation and analysis

Plant samples (straw and grain samples) were collected finally at threshing and winnowing which includes grain and all the remaining above ground plant part (straw) in separate sample from each experimental unit. The straw and grain samples were milled and sieved through 0.5-mm size sieve. Prepared sample were tested under HARC plant and soil analysis laboratory. Samples were tested for their P, N and S concentration within the plant biomass.

Soil sampling and analysis

Several soil samples were randomly taken at surface (0-20 cm depth) to assess the physicochemical properties and the dynamics of the study soils during the field experiment. Fifteen samples were collected before experiment was set up and then bulked into one composite, while after the experimental crop was harvested, soil samples were collected treatment-wise to evaluate the effect of treatments on major soil acidity attributes like pH and exchangeable acidity and to assess the residual effect of the treatment application on soil physicochemical properties.

Physical property determination: Soil sample collected from the study area was examined for its textural class by using hydrometer method of soil particle size distribution determination at HARC soil and plant tissue analysis laboratory. The soil bulk density (apparent density) of the study site was determined by taking core sample from each experimental site and using undisturbed method of BD determination.

Chemical property determination: Determination of soil pH is done by H_2O method with 1:2.5 ratio soil to water suspension; Exchangeable acidity (EA) of the study area soil sample was determined by using Van Reeuwij k, L.p 1N KCl leaching titration method (Sarkar and Haldar, 2005). Organic carbon (OC %) was determined by using Walkley-Black chromic acid wet oxidation method (Sarkar and Haldar, 2005). Total nitrogen (TN) was determined by using Kjeldhal Bremner and Mulvancy method. Soil extractable P (Brey II method was used which is the same as Bray I procedure of extractable P determination except that the concentration of HCl in Bray II is increased to 0.1 N from 0.025 N. It is appropriate for acidic soil and for soil samples where RPs are used as P fertilizer. Cation exchange capacity (CEC) was determined by using ammonium acetate extraction method whereas soil available sulfate-sulfur (SO_4-S) was determined by using turbidimetric method (Sarkar and Haldar, 2005).

Composite soil sample from both experimental locations was analyzed for their basic cations, that is, exchangeable potassium (K^+), Magnesium (Mg^{2+}), Sodium (Na^+) and Calcium (Ca^{2+}) by using ammonium acetate method of extraction which is appropriate for acidic to slightly alkaline soil types. Then the extract was read using instruments, for K^+ and Na^+ Flame Emission Spectro Photometer (FESP); and for determination of Ca^{2+} and Mg^{2+}, Atomic Absorption Spectro Photometer (AASP) apparatus was used. Boron (B) was determined using dilute hydrochloric acid method which is more suitable for acidic soil types (Sarkar and Haldar, 2005).

C:N ratio indicates the general process undertaken in the soils of study site related to N during decomposition of OM and effectiveness of applied N fertilizers to crop utilization. It was computed by directly taking the result of C and N in the examined soil sample; Percent acid saturation (PAS) of the soil was computed from the ration of exchangeable acidity (EA) to the CEC multiplied by 100 which is the part of cation exchange site occupied by the H^+ and Al^{3+} ions that contributes to the EA properties of soil (Fageria et al., 2007).

Economic analysis

Partial budget analysis

Economic analysis was done for each treatment through evaluation of cost and return, and benefit to cost ratio was calculated according to the procedure given by CIMMYT (1988). Variable input was identified for each treatment which requires different input and labour costs for its practical implementation on farmers' field in hectare bases. It includes lists of variable input data related to price of lime, different types of P fertilizers and other sources of essential nutrient used, cost incurred for transport, labor cost for field managements and application of those inputs and land preparation. The price of barley grain and straw after harvest were taken into account to undertake cost-benefit analysis. The marketable grain and biomass/straw yield from the control plot (no lime and fertilizer input) was taken as a reference and the yield increment at different treatments that received different type and rates of input was considered for evaluation. The average market price of barley grain and straw yield in the local market of the area was 1000.00 and 35.00 ETB Qt^{-1} respectively. The minimum acceptable marginal rate of return used in this study was assumed to be 50% for farmers' recommendation domain. Finally, the treatment that gave the maximum benefit cost ratio was selected. The economic analysis was based on the formula developed by CIMMYT (1988).

Average grain and biomass yield (AGY and ABY) (kg ha^{-1} or t ha^{-1}): Is an average grain and biomass or straw yield of each treatment since both of them are the marketable products.

Adjusted grain and biomass yield (AJG and AJB): Is the average grain and biomass yield adjusted downward by 10% to reflect the difference between the experimental yield and yield of farmers.

$$AJG = AGY - (AGY \times 0.1)$$

$$AJB = AJB - (AJB \times 0.1)$$

Gross field benefit (GFB): This was computed by multiplying field/farm gate price that farmers receive for the grain and straw

Table 4. Physico-chemical properties of both experimental site soil samples before planting (treatment application).

Location	pH	TN (%)	K Cmol (+) kg^{-1}s	AP (ppm)	Mg Cmol (+) kg^{-1}s	OC (%)	Ca Cmol (+) kg^{-1}s	Na Cmol (+) kg^{-1}s	EA Cmol (+) kg^{-1}s	CEC (meq/100 g)
OnS	5.14	0.143	1.262	4.36	4.01	1.13	6.8	0.145	0.978	19.6
OnF	4.24	0.134	1.978	7.86	4.67	1.76	8.3	0.0825	1.367	27.4

TN= total nitrogen, AP= available P, OC =organic carbon, EA= exchangeable acidity, OM= organic matter. Meq 100 g^{-1} soil = Cmol (+) kg^{-1} of soil.

yield when they sell it as adjusted yield.

GFB = (AJG × Field/Farm gate price of barley grain) + (AJB × Field/Farm gate price of straw)

Total cost (TC): Is the cost of inputs used in the experiment as mean current prices of lime, different types of fertilizer, wage for lime and fertilizers application, and transport were considered per hectare.

Net benefit (NB): This was calculated by subtracting the total costs from the gross field benefit for each treatment.

NB = GFB – TC

Marginal cost (MC) = Change in costs between treatments.

Marginal benefit (MB) = Change in net benefits between treatments.

Dominance analysis: This is done by sorting total variable cost of each treatment in ascending order and then computing the difference in cost (C) and benefit (B) of each successive treatment as described in CIMMIT (1988) procedure to calculate the marginal rate of return and treatments dominance. Any treatment that has net benefits which are less than or equal to those of a treatment with lower costs that vary is dominated (Stephen and Nicky, 2007).

Marginal rate of return (MRR): The process of calculating the MRR of alternative treatments, sorted from the least costly treatment to the costliest ones, and deciding if they are acceptable to farmers, is called marginal analysis; in other words, it is the slope of net benefit curve between two successive treatments. %MRR was calculated as changes in net benefit (raised benefit) divided by changes in cost (raised cost).

% MRR = (MB / MC) × 100

Statistical analysis

Agronomic data, grain quality parameters and plant tissue analysis results were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS version-9.0) to evaluate the impact of different P fertilizer source with different lime and fertilizer application rates. Results were presented as means with Least Significance Difference (LSD) at 5% probability level (Steel et al., 1997). Over location combined data of some parameters was done since largest standard error SE to least SE ratio was below 3 which indicates its homogeneity across experimental locations (Gomez, 1984).

RESULTS AND DISCUSSION

Preliminary soil physico-chemical properties of study area

The soil analysis results of the study areas showed that N, P, S and B were more limited than other essential mineral nutrients (Table 4) as confirmed by EthioSIS, (2014) soil fertility map, whereas the remaining essential mineral nutrients are found relatively in higher and sufficient levels.

Soil physical properties

The mean soil particle size distribution results for each composite soil sample was 50% clay, 18.8% silt and 31.3% sand for on-station site (OnS) which is classified as “Clay” textural class (Table 4) whereas the on-farm site (OnF) had an average content of 37.5% clay, 20% silt and 42.5% sand. Consequently, it was grouped as the “clay loam” textural class (USDA, 2008). Both study sites soil physical properties were categorized under fine texture class, much influenced by their higher amount of clay particles, which in turn influences the physical and chemical properties of such soils. Thus, organic inputs application influences its erosion response and physical environmental impacts. It also has several impacts on the P fixation, nutrient holding capacity, buffering capacity and other chemical properties related to productivity of such soils (Morel et al., 1989).

Soil chemical properties

For OnS samples, the mean pH reading was 5.14, which is categorized as ‘strongly acidic property according to USDA/NRCS (1998) rating, while for the OnF, the average pH was 4.24, which is virtually the same category with the OnS with their soil pH results. Mean exchangeable acidity (Al^{3+} and H^{+}) results for both locations soil samples were 0.978 and 1.367 Meq 100^{-1} g of soil for OnS and OnF site respectively (Table 4) which are quite representative for soil acidity. The OnS site EA level exceeds by 1 Meq 100^{-1} g of soil. As reported by several authors, soil pH value with <5.5 usually have problems of Al toxicity or acidification, but can be improved by amendment practices like application of lime, compost or organic manure (Scherr and Yadav, 1996). Upon liming, Alvarez et al. (2009) reported decreases of Al^{+3} in the soil solution as well as in the exchangeable complex which creates conducive soil environment for potential crop production.

Available P (AP ppm) for OnS and OnF sites were 4.34 and 7.85 ppm respectively. The level of AP in each study site can be categorized as low since their results were far below 15 ppm (Jones, 2011); or for <5 ppm and 6-12 ppm range they were categorized as very low and low AP ratings respectively. So, we can generally categorize the experimental sites as deficit based on their soil available P level.

Organic Carbon (OC%) for Holeta on-station (OnS) was 1.13%, while on-farm (OnF) OC content was found to be 1.76% on average. When OC was converted to organic matter, the percentage of total soil OM becomes 1.95 and 3.03% for the two experimental sites respectively, and the results were categorized under low level of OC or OM according to Brook (1983). The OnS and OnF study sites had an average total N value of 0.142 and 0.134% respectively, both of which are categorized under medium range of N level according to Brook (1983), since the categorized total N ranges from 0.12 - 0.18% under medium TN rating.

Cation Exchange Capacity (CEC): Mean result for the two experimental sites was recorded to be 19.6 and 27.4 Meq 100^{-1} g of soil for OnS and OnF sites respectively. They are categorized under medium and high level of CEC classification which is most common values for heavy texture soils. These can highly correlate with their pH buffering and other chemical properties majorly related to soil fertility.

Effects on barley growth performance and phenology

Most of the agronomic parameters of barley were significantly ($p<0.05$) influenced by application of different phosphorus sources of fertilizers, except spike length (SPL) and number of spikelets per spike (NSK). All barley growth parameters were non-significantly affected by phosphorus fertilizer rates. Lime application significantly ($p<0.05$) influenced spike length, number of spikelets per spike and total number of tillers per plant, but not other parameters. In contrast, all barley agronomic parameters except plant height and number of spikelets per spike were significantly different between the two locations.

Plant height and number of tillers per plant

On this growth parameter, the data were collected in two forms, viz; total number of tillers per plant and number of effective tillers per plant, both of which showed the same response. Application of different P fertilizers types showed significant ($P<0.05$) influences on plant height. Accordingly, the highest mean value (103.7 cm) was obtained from NPSB source of P fertilizer followed by MOHP with 101.7 cm which was statistically at the same performance with the first set of P source of fertilizer (Table 5). The least plant height (99.5 cm) resulted from control treatment. Although there was no significant difference between P application rate 69 kg ha^{-1}, P_2O_5 showed relatively higher plant height mean result. In the case of lime application, the variance is not significant. In general, from treatment combination of NPSB, at 69 kg ha^{-1}, P_2O_5 (PR2) rate with lime application (LM2) gave the highest number of tiller and PH superior result over other set of treatments as indicative of best crop growth performance. These results supplemented the research findings of Getachewu (2005) which showed that the use of efficient P fertilizer significantly increased the plant stand count (tillering capacity) and plant height.

Different phosphorus fertilizer and lime application significantly ($P<0.05$) affected the number of total and effective tillers per plant. Accordingly, the treatment P3 or NPSB source of p fertilizer got the better TT and ET (5.6 and 4.65 number of tillers respectively) on average than other sources of phosphorus fertilizer. On the other hand, application of lime also result to significant ($P<0.05$) difference on both total and effective number of tillers, so the lime treated set of treatments LM2 have got superior numbers of tillers than un-treated ones with a mean result of 5.1 and 4.2 respectively (Table 5). As reported by several authors, yield components of barley such as number of tillers per plant, number of spikelets per spike, AGB and TSW were highly correlated with its grain yields (Temesgen et al., 2016), confirmed the effects of lime and P fertilizer effects on yields of barley, and as also verified in this study, it is most likely related to the phosphorus availability and use efficiency of the plant as affected by application of lime and varied soluble phosphorus fertilizer sources which in turn improves the root growth of barley and will also improve productivity and vegetative growth as implied in plant height and tillering improvement.

Spike length and number of spikelet per spike

Application of lime significantly ($P<0.05$) increased the spike length and number of spikelets per spike. Accordingly, LM2 showed superior spike length advantage over LM1 set of treatments in average 2.1 mm spike length advantage for all treated with lime LM2. Application of different p sources and phosphorus fertilizer rate showed significant spike length difference. The number of spikelets per spike (NSK) was significantly ($P<0.05$) affected by application of lime. Accordingly, the highest number of spikelets obtained from single spike was 47.9 in average for lime treated (LM2) and 45.8 for the untreated set of treatments LM1 which is a statistically significant ($P<0.05$) difference (Table 5). As several research findings revealed, spike length can be a major yield component affected by soil acidity and can be improved through application of lime (Foy and Flaming, 1978). A major characteristic of Al toxicity in acidic soil is an inhibition of the uptake and translocation of Phosphorus by plants, thus liming increase p uptake of

Table 5. Major barley growth parameters as affected by different P sources of fertilizer, P rate, lime application and location sources of variability.

Source of variability		PH (cm)	SPL (cm)	NSK	TT	ET	DF	DM
Location	OnS	101.41	7.2^{A}	46.9	5.17^{A}	4.34^{A}	98.13^{A}	135.7
	OnF	101.41	6.6^{B}	46.7	4.17^{B}	3.16^{B}	85.2^{B}	135.6
LSD		Ns	0.16**	Ns	0.47**	0.39*	3.4**	Ns
P Sources	PARP	100.8^{B}	6.90	47.2	4.4^{B}	3.49^{B}	92.7^{B}	133^{BC}
	MOHP	101.7^{AB}	6.99	47.5	4.3^{B}	3.35^{B}	98.7^{A}	138.3^{AB}
	NPSB	103.7^{A}	6.78	45.7	5.6^{A}	4.65^{A}	75.4^{C}	139.7^{A}
	NAFAKA+	99.5^{B}	6.90	46.8	4.4^{B}	3.51^{B}	99.9^{A}	131.4^{C}
LSD		2.68 *	Ns	Ns	0.67*	0.55**	4.8**	5.41*
P. Rate	34.5 kg ha^{-1}	101.4	6.87	46.4	4.5	3.58	93.2	137.2
	69 kg ha^{-1}	101.5	6.92	47.2	4.8	3.92	90.1	134.1
LSD		Ns	Ns	Ns	Ns	Ns	Ns	Ns
Lime	LM1	101.2	6.79^{B}	45.8^{B}	4.2^{B}	3.39^{B}	90.5	134.3
	LM2	101.6	7.0^{A}	47.9^{A}	5.1^{A}	4.10^{A}	92.9	136.9
LSD		Ns	0.16 *	1.3 **	0.47**	0.385*	Ns	Ns
Control		92.7	6.47	43.5	3.9	3.1	107.2	149.5
CV (%)		4.6	5.8	7.05	24.8	25.2	9.1	6.9

Means with the same letters have no significant difference b/n each other Ns not significant, * significant at $P<0.05$ ** highly significant at $p<0.01$ and *** significant @ $P<0.001$. PH plant height in cm, SPL spike length, NSK number of spikelets per spike, TT total number of tillers per plant, ET effective tiller per plant. DF, DM- date of flowering and maturity respectively.

plant by decreasing Al toxicity rather than by affecting soil P availability percent (Hynes and Ludecke, 1981) which busts the barley productivity by enhancing the metabolic activity for proper physiological maturity. On the other hand, an application of different sources of P fertilizers MOHP with application rate 69 kg ha^{-1} P_2O_5 gave higher number of spikelets.

Number of days to flowering and maturity

The preferable result in date of flowering (DF) and date of maturity (DM) parameters were identified as the treatment which requires moderate ranges of days depending on the barley variety used whether it is late set or early set (the right/optimal number of days required to flowering and maturity for barley BH-1307 variety is 80 and 135 days respectively as specified in the variety description). Accordingly, application of different sources of phosphorus fertilizer and different experimental locations sources of variability significantly ($p<0.05$) influenced the number of days required for flowering and maturity in more than 75% of plant population within each plot in appropriate time. 75.4 days to flowering was required by NPSB blended fertilizer P source which approaches varieties optimal requirements.

On the other hand, DM (number of days to maturity) was significantly ($P<0.05$) affected by application of diversified sources of P fertilizers. Both delayed and forced maturity was observed in some of the experimental units due to different treatment factors majorly induced from nutrient deficiency/imbalance and limitation effects on their nutrient use efficiency. Accordingly, the optimal DM was obtained from MOHP and NPSB sources of phosphate fertilizer with 138.3 and 139.7 average number of days respectively (Table 5). Getachewu (2005) also showed that P fertilizer application improves number of days required to heading and maturity of barley crop.

Effects on biomass, grain yields and grain physical qualities of barley

Above ground dry biomass

Above ground dry biomass (AGB) of barley was significantly ($p<0.05$) affected by phosphorus fertilizer

Table 6. Above ground dry biomass, grain yield and some grain quality parameters of barley as affected by different P sources, P rate, lime application and location sources of variability.

Source of variability		AGB (kg ha^{-1})	GY (kg ha^{-1})	TSW (g)	HLW (kg/hl)	MST (%)
Location	OnS	7517^{A}	3403.2^{A}	43.8^{A}	65.6^{A}	10.36^{B}
	OnF	5953^{B}	2491.4^{B}	41.2^{B}	63.9^{B}	11.10^{A}
LSD		507***	200.1***	0.7**	0.82**	0.11*
P Sources	PARP	6639^{B}	2888.9^{B}	42.4^{B}	64.83	10.74
	MOHP	6446^{BC}	2737.4^{BC}	41.9^{B}	64.78	10.70
	NPSB	8054^{A}	3601.4^{A}	44.1^{A}	65.33	10.64
	NAFAKA	5803^{C}	2561.6^{C}	41.5^{B}	64.20	10.85
LSD		717***	282.9***	1.0**	Ns	Ns
P. Rate	34.5 kg ha^{-1}	6496	2854.1	42.6	65.2	10.72
	69 kg ha^{-1}	6974	3040.6	42.4	64.4	10.74
LSD		Ns	Ns	Ns	Ns	Ns
Lime	LM1	6456^{B}	2842.5^{B}	42.7	64.9	10.72
	LM2	7015^{A}	3025.2^{A}	42.3	64.6	10.74
LSD		507 *	200.1*	Ns	Ns	Ns
Control		4183.6	1906.6	38.27	60.85	10.70
CV (%)		18.4	16.6	4.2	3.09	2.57

Means with the same letters have no significant difference; Ns: not significant, * Significant at P<0.05, ** highly significant at p<0.01, and *** significant at P<0.001. AGB: Above ground dry biomass, GY: grain yield, TSW: 1000-seed weight, HLW: hectoliter weight, and MST: gain moisture percentage.

sources, P fertilizer rate and by lime application rate. The highest AGB (8 t ha^{-1}) was attained when P3 (NPSB) source of P fertilizer was applied followed by P1 (PARP) with 6.6 t ha^{-1} (Table 6). It was attributed to immediate availability of high-grade water-soluble P fertilizer source blended in NPSB P source. Also, Szilas et al. (2006) confirmed that there was faster dissolution of the high-grade water-soluble P source of fertilizer than MPR (Minjingu phosphate rock) or low solubility P fertilizers from PRs resulting in more available after water soluble p fertilizer than after MPR application. The plant part analysis and P uptake results was also supported by this result. A superior mean result in both cases was obtained from NPSB sources of P fertilizer.

Practice of partly acidulated or direct application of PRs gave competent result with high grade soluble P fertilizers as studied by Szilas et al. (2006) who found that direct application of PRs except for the first two seasons of study where MPR was slightly inferior to TSP (high-grade water-soluble P fertilizer) in a long-term use MPR or PARP can replace high grade soluble P fertilizers on acid soils.

Lime treated plots LM2 produced on average 8.7% above ground biomass yield advantage over un-treated ones LM1 (Table 6). This result supported the research findings of Desta (1987) which approved that the application of lime markedly increased the yield of barley by improving soil pH and plant nutrient availability, especially P. Similarly, other findings presented higher biomass and other related agronomic traits were improved by using lime with P application in acidic soils of Ethiopia (Temesgen et al., 2016).

Grain yield

Application of different sources of phosphorus fertilizer significantly (P<0.05) influenced grain yield (GY) of barley at both experimental sites. The highest average grain yield (3601 kg ha^{-1}) was obtained from NPSB followed by 2888.9 kg ha^{-1} GY from PARP source of P fertilizer (Table 6). The least GY (1906.6 kg ha^{-1}) was obtained from control treatment. NAFAKA P-source only improved GY by 34.4% compared to control treatment far below 88.9% compared with GY improvement from application of superior NPSB treatment (Figure 4). These results

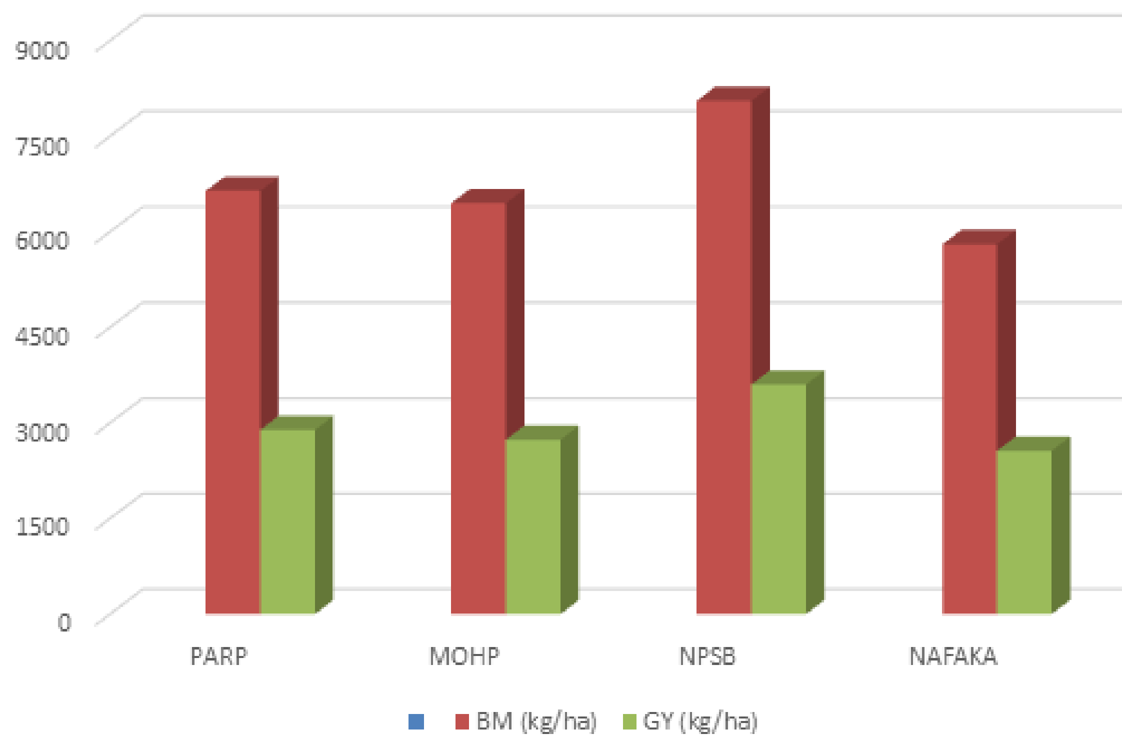

Figure 4. Grain and biomass yield of barley crop as affected by different sources of phosphorus fertilizers in Welmera district.

support the finding of Ester et al. (2014) who could observe different crop performance in response to different sources of Phosphorus fertilizers application. Indeed, the available or water soluble P_2O_5 content was varied to provide immediate use and gradual release of P in available forms to plant uptake. This improves suitable supply for the crop uses instead of fixation by such acidic soils into unavailable forms. The competitive result obtained from PARP fertilizer supports the findings of Chien and Menon (1995) in which several field trials conducted by IFDC in Asia, sub-Saharan Africa, and Latin America have demonstrated that PARP at 40-50% acidulation with H_2SO_4 or at 20% by H_3PO_4 approaches the effectiveness of SSP/TSP (high-grade water-soluble P sources of fertilizer) in certain tropical soils and crops.

Lime application at LM2 rate produced significantly (P<0.05) higher GY (3025.2 kg ha^{-1}) as compared to un-limed LM1 treatment average GY (2842.5 kg ha^{-1}) result (Table 6) which was also reported by Meng et al. (2004) in which significant yield increment were obtained using lime on acidic soils. On the independent result of each experimental site, at OnS, superior GY (4746.7 kg ha^{-1}) resulted along with other most agronomic parameters when NPSB was applied at 69 kg ha^{-1} P_2O_5 treated with lime. This is approximately the maximum yield potential (that is, 30-50 Qt ha^{-1}) of food barley variety BH-1307. Comparatively, this treatment produced about 10.7% grain yield advantage over the other treatment combination that emerged along with 2146 kg ha^{-1} or 82.5% GY advantage over control (no fertilizer and lime). On the other hand, significantly (P<0.05) different yield improvements resulted from OnS than OnF sites due to favors on the routine crop management practice and follow up starting from land preparation up to harvesting whereas the OnF site was treated like common farmers' management practices.

Grain quality parameters like thousand seed weight (TSW), hectoliter weight (HLW) and grain moisture (MST) content were significantly (P<0.05) affected by application of different sources of phosphorus fertilizer and experimental location variability. All of the above quality parameters showed significantly (P<0.05) higher result at OnS experimental location. From different sources of P fertilizer, NPSB was found superior TSW (44.1 g). Other parameters were not significantly (P<0.05) affected by P sources. Lime application and rate of P fertilizer also could not affect any of the considered grain quality parameters significantly.

Generally, use of NPSB fertilizer at 69 kg ha^{-1} P_2O_5 rate with lime application can give maximum yield of barley under acidic soils of Wolmera. PARP at the application of 69 kg ha^{-1} P_2O_5 produced comparable GY and AGB with lime application. These findings supplement the research result of Shiferaw and Anteneh (2014) which have also indicated that half dose of recommended lime application with balanced fertilizer significantly increased barley yield

Table 7. Interaction effects of different agronomic parameters of barley as affected by different sources of P fertilizer and lime application.

Level of significance	PH	SPL	NSK	DF	DM	AGB	GY	HLW
* (P ≤ 0.05)	L×LM		L×PS×PR×LM					
** (P < 0.01)			L×LM		L ×PS	L×PS	L×LM	L×LM
*** (P < 0.001)		L×LM		P×L×LM				

PH- plant height, SPL- spike length, NSK- number of spikelets per spike, AGB- above ground biomass, GY- grain yield, DF- date of flowering, DM-days to mature, HLW- hectoliter weight, PS- P source, L- location, LM- lime rate, PR- phosphorus rate.

Table 8. Plant P, N and S concentration as affected by the application of lime, P sources and P rates.

Source of variation		Biomass P (%)	Grain P (%)	P Bs (kg ha^{-1})	P Gy. (kg ha^{-1})	PHI (%)	N (%)	S (%)
P sources	PARP	0.063	0.255	2.405^{B}	7.37^{B}	76.6	1.206	0.088
	MOHP	0.066	0.232	2.554^{B}	6.598^{B}	73.8	1.198	0.098
	NPSB	0.071	0.252	3.276^{A}	9.45^{A}	74.6	1.221	0.090
	NAFAKA	0.070	0.228	2.376^{B}	6.13^{B}	72.9	1.239	0.095
LSD		Ns	Ns	0.61	1.68	Ns	Ns	Ns
Fertilizer rate	PR1	0.067	0.2417	2.549	7.13	74.7	1.204	0.089
	PR2	0.068	0.2418	2.757	7.69	74.2	1.229	0.096
LSD		Ns	Ns	Ns	Ns	Ns	Ns	Ns
Lime	LM1	0.065	0.242	2.33^{B}	7.028	75.4	1.175	0.091
	LM2	0.070	0.241	2.97^{A}	7.79	73.5	1.257	0.094
LSD		Ns	Ns	0.42	Ns	Ns	Ns	Ns
Location	OnS	0.094^{A}	0.288^{A}	3.89^{A}	9.92^{A}	71.6^{A}	1.198	0.078
	OnF	0.041^{B}	0.195^{B}	1.42^{B}	4.89^{B}	77.4^{B}	1.234	0.108
LSD		0.006	0.021	0.43	1.19	3.17	Ns	Ns
Mean		0.0674	0.242	2.65	7.41	74.5	1.21	0.093
CV %		12.9	11.9	22.18	22.08	5.84	12.14	24.1

P.Bs- P uptake in plant biomass, P.Gy- P uptake in barley grain yield. Means with the same letter don't have significant difference each other, PHI-phosphorus harvest index, N%- nitrogen concentration, S%- sulfur concentration.

under acidic soil condition.

From interaction analysis result, SPL and DF of barley was significantly (p<0.001) affected by location and application of lime (LM) interaction (Table 7) as a result of different edaphic factors shown in Table 3. PH and NSK growth parameters were significantly (p<0.05) affected by (L×LM) and (L×PS×PR×LM) interaction factors respectively. On the other hand, SPL and DF was significantly (p<0.001) affected by location and lime application interaction effects (Table 7). Another study also showed that application of lime in different soil types and locations responded differently depending on its physicochemical properties (Kumar, 2012).

Effects on plant nutrient concentration and phosphorus uptake

Phosphorus concentration in the straw and grain of barley were non-significantly (P<0.05) influenced by P sources, rates and lime application (Table 8). On the other hand, P concentration was significantly different between the two experimental locations. P uptake in the straw and grain of barley was significantly affected by P

Table 9. Effects of P sources of fertilizer and lime application on Partial budget analysis, gross field benefit and net benefit of barley in Wolmera district of Oromia regional state.

Treatment			AGB	GY	ABM	AGY	TVC	GFB	NB
PS	PR	LM	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(USD ha^{-1})	(USD ha^{-1})	(USD ha^{-1})
P0	PR0	LM1	4183.6	1908.6	3765.21	1717.78	0.00	677.49	677.49
P1	PR1	LM1	6407.1	2892.1	5766.39	2602.89	117.20	1027.37	910.17
p1	PR2	LM1	6575.8	2781.7	5918.22	2503.53	127.31	992.92	865.61
P2	PR1	LM1	6161.9	2567.1	5545.71	2310.39	125.38	917.40	792.01
P2	PR2	LM1	6434.2	2612.3	5790.78	2351.07	143.43	935.44	792.00
P3	PR1	LM1	7270.2	3302.3	6543.18	2972.07	102.25	1172.56	1070.31
P3	PR2	LM1	8194.3	3849.4	7374.87	3464.46	142.40	1363.58	1221.19
P4	PR1	LM1	5373.9	2500.8	4836.51	2250.72	73.51	886.45	812.94
P4	PR2	LM1	5232.2	2234.2	4708.98	2010.78	84.81	796.92	712.11
P1	PR1	LM2	6463.6	2707.9	5817.24	2437.11	143.42	967.29	823.87
P1	PR2	LM2	7107	3174.1	6396.30	2856.69	153.53	1128.41	974.88
P2	PR1	LM2	6423.6	2873.8	5781.24	2586.42	151.61	1021.53	869.91
P2	PR2	LM2	6765.4	2896.3	6088.86	2606.67	169.66	1032.89	863.22
P3	PR1	LM2	7684.2	3291.7	6915.78	2962.53	128.48	1173.84	1045.36
P3	PR2	LM2	9067.5	3962.3	8160.75	3566.07	168.62	1410.88	1242.25
P4	PR1	LM2	6188.2	2697.2	5569.38	2427.48	99.74	960.59	860.85
P4	PR2	LM2	6415.5	2814.3	5773.95	2532.87	111.03	1001.82	890.78

P0PR0LM1- for the control treatment, PS- P fertilizer type, PR- phosphorus rate, LM- lime rate, GY- average grain yield, AGB- above ground biomass/straw yield, AGY- and ABM- for adjusted grain and straw yield, TVC- total variable cost, GFB- gross field benefit, NB- net benefit in US Dollar per ha with 27.3 ETB exchange rate.

sources and locations. N and S concentration and uptake in the straw and grain of barley were non-significantly (P<0.05) influenced by P sources, rates and lime application. From the result, P uptake in straw and grain was significantly (P<0.05) affected by application of different P sources. The superior result (3.27 and 9.45 kg ha^{-1} P) biomass and grain P uptake respectively, was obtained from P3 (NPSB) source of P fertilizer. According to Mengel and Kirkby (1987), the nutrient content of plant tissue reflects soil availability, low P uptake and concentrations in plant materials attributed to low P availability in the experimental soil. Thus, phosphorus availability to plants is determined by the chemical characteristics of the soil and the P fertilizer source (Havlin, 1999). Hammond et al. (1986) studied the influence of the chemical characteristics of four PRs from different location with varied solubility of P_2O_5 content on dry matter yield of corn grown on two different soils. They found a good correlation (r=0.92) between P uptake and water-soluble P contents from the PAPR 50% H_2S0_4 and concluded that the crop responded to the water-soluble P rather than to the citrate-soluble P. Significantly highest P concentration and uptake in barley biomass and grain were obtained from OnS experimental location like other supplementary yield and plant nutrient concentration results.

Percentage of P concentration in plant tissue mean result was majorly affected from different sources of P fertilizers with the highest percent of P concentration in plant tissue obtained from P3. Application of lime significantly (P≤0.05) affects phosphorus uptake in the above ground plant biomass, which is higher at treatment with lime application (LM2). Similarly, other parameters also got supplementary response to application of lime (Table 8). Higher application rate of P at (PR 2) brought improved P uptake, just like other studies that indicated that the level of nutrient fertilization affects the nutrient availability in soil; and at high contents of soil nutrients and their availability, more nutrients might be taken up by plants (Sandana, 2016). P uptake index result did not show significant difference except location sources of variability in which OnF site have got better mean result (77.4%) than the OnS site.

Economic analysis results

Partial budget analysis

As the net benefit result showed (Table 9), the highest NB 1242.25 USD ha^{-1} was obtained when NPSB at 69 P_2O_5 kg ha^{-1} was applied with lime (LM2), which is 83.4% improvement over the control treatment (lime and P was not applied) followed by 80.3% net benefit from treatment combination P3, PR2 and LM1; 58% from treatment combination NPSB 34.5 kg ha^{-1} P_2O_5 0 lime; 54.3% from

Table 10. Dominance and marginal rate of return analysis result on application of lime and different P sources of fertilizers.

Treatment			TVC (USD ha^{-1})	GFB (USD ha^{-1})	NB (USD ha^{-1})	Dominance	C	B	MRR %	B:C ratio
PS	RT	LM								
P0	PR0	LM0	0	677.49	677.49					
P4	PR1	LM1	73.51	886.45	812.94		73.51	135.44	184.25	0.122
P4	PR2	LM1	84.81	796.92	712.11	Dominated				
P4	PR1	LM2	99.74	960.59	860.85		26.23	47.92	182.70	0.172
P3	PR1	LM1	102.25	1172.56	1070.31		2.51	209.46	8337.16	0.200
P4	PR2	LM2	111.03	1001.82	890.78	Dominated				
P1	PR1	LM1	117.2	1027.37	910.17	Dominated				
P2	PR1	LM1	125.38	917.4	792.01	Dominated				
P1	PR2	LM1	127.31	992.92	865.61	Dominated				
P3	PR1	LM2	128.48	1173.84	1045.36	Dominated				
P3	PR2	LM1	142.4	1363.58	1221.19		40.15	150.88	375.81	0.205
P1	PR1	LM2	143.42	967.29	823.87	Dominated				
P2	PR2	LM1	143.43	935.44	792	Dominated				
P2	PR1	LM2	151.61	1021.53	869.91	Dominated				
P1	PR2	LM2	153.53	1128.41	974.88	Dominated				
P3	PR2	LM2	168.62	1410.88	1242.25		26.23	21.07	80.33	0.363
P2	PR2	LM2	169.66	1032.89	863.22	Dominated				

PS- P sources (P1: PARP, P2: MOHP, P3: NPSB and P4: NAFAKA), PR- P fertilizer rate (PR1: 34.5 kg ha^{-1}, PR2: 69 kg ha^{-1}), LM- lime application (LM1 without lime, LM2: with lime).

F3, PR1, LM2; and 43.9% net benefit advantage from treatment P1, PR2 and LM2.

In general, the net economic benefit result showed that the NPSB source of P fertilizer have got superior advantage over other fertilizer types followed by the PARP source of P fertilizer in combination with lime application.

Dominance analysis and marginal rate of return

The dominant analysis result showed that the net benefits of most listed treatments in the dominance table were dominated. This indicate that the net benefit decreased as the total cost that varies increased beyond undominated lime and P fertilizer treatments application in different rates. The computed %MRR result showed the highest marginal rate of return result 8337.16% was obtained from treatment combination NPSB fertilizer with 34.5 kg ha^{-1} P_2O_5 application rate on mean values of both experimental locations (Table 10). According to CIMMIT (1988) most commonly on fertilizer trials, minimum rate of return used are 100%; consequently all un-dominated set of treatment combinations except the least ones have % MRR values that were more than the minimum acceptable ones for fertilizer experiment.

From lists of un-dominated treatments, the next higher 375.8 %MRR result was found from treatment combination NPSB with application rate of 69 kg ha^{-1} P_2O_5 without lime LM1; then finally, the least MRR result was from the same treatment which differs on the application of lime with LR2. With 80% MRR, this treatment got the highest net field benefit in cash from all other treatment combinations. On the other hand, the only other P source which have un-dominated higher 184.3 and 182.7% MRR result is NAFAKA blend fertilizer without (LM1) and with (LM2) application of lime respectively, both of which has 34.5 kg ha^{-1} P_2O_5 application rate.

Conclusion

Field experiment was conducted to assess and evaluate the effects of different phosphorus sources and their application rate with and without lime on agronomic performance of food barley (*H. vulgaer* L.) at Holeta (on-station) and Rob Gebeya (on-farm), which are located in Wolmera district of "*Finfine Zuria*" special zone of Oromia region under rain fed condition during '*Meher*' season in 2017. This experiment has three factors laid out in factorial RCBD arrangement with three replications. The treatments consisted of four different P sources (granular partially acidulated rock phosphate PARP, organic hyper phosphate MOHP, blended fertilizer formula - II (NPSB) and NAFAKA plus complete blended fertilizer); two application rates of the phosphorus fertilizer (34.5 and 69 kg P_2O_5 ha^{-1}) and two lime rates (limed and without lime). A total of 16 experimental treatments were evaluated with three replications under two locations.

The preliminary soil analysis results indicated that: experimental sites had clay and clay loam textural class with 1.02 and 1.14 g/cm^3 bulk density respectively for OnS and OnF sites at surface (0-20 cm depth). The soil test result indicated that it was strongly acidic pH; medium range of total nitrogen; low in OC%, high in available K^+; very high and high concentration in Ca^{2+} and Mg^{2+}; medium rate of SO_4/S and marginal to low in its boron levels for both testing sites. The soil test results also revealed very low and low in its available phosphorus, medium and high in CEC, very high and high in percent base saturation (PBS) level respectively at on-station and on-farm experimental sites.

ANOVA result confirmed that using different source of Phosphorus fertilizer significantly (p<0.05) affected plant height, number of tillers per plant, date of flowering and maturity, above ground biomass, grain yield and 1000-seed weight. Application of NPSB as P source substantially improved the agronomic parameters like PH, TT, ET, DF, DM, AGB, GY and TSW by 11.9, 43.6, 50, 41.9, 7, 92.5, 88.9 and 15.2% respectively over the control treatment. As an alternative, PARP source of P fertilizer also resulted in remarkably competent biomass (58.7%) and grain yield (51.5%) improvement over the control treatment.

On the other hand, application of lime also significantly (P<0.05) improved spike length, number of spikelets per spike, number of total and effective tillers per plant, above ground biomass and grain yield with 3, 4.5, 21.4, 20.9, 8.6 and 6.4% improvements respectively for all experimental sites on average. Even if application rate of P_2O_5 did not significantly affect agronomic parameters, higher P fertilizer rate at 69 kg ha^{-1} P_2O_5 showed superior mean results on considered agronomic parameters, thus use of varied forms of phosphorus fertilizers from organic and inorganic blended form improved the productivity of acidic soil with lime application and can provide competent crop performance with higher grade water soluble fertilizers by promoting slow release of plant available phosphorus as it improves crops nutrient use efficiency and physical qualities of barley grain in balanced soil fertilizer management. It is mandatory to seek the alternative sources of phosphate fertilizer since the dominantly existing sources become less efficient especially on acidic soils and its natural reserves became depleted. In these regards, alternative sources with competent economic advantage and less environmental impacts should be considered as a great success for sustainable agricultural productivity to insure food security for ever increasing world population.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Alemayehu K, Sheleme B, Schoenau J (2017). Fractionation and availability of phosphorus in acid soil of Hagereselam, southern Ethiopia under different rate of lime. Chemical and Biological Technologies in Agriculture 4(1):1-7.

Alvarez CR, Taboada MA (2009). Top soil properties as affected by tillage systems in the Rolling Pampa region of Argentina. Soil Science Society of America Journal 73(4):1242-1250.

Amsal T, Tanner DG, Amanuel G, Tilahun G, Zewdu Y (1997). The effect of several crop management factors on bread wheat yields in the Ethiopian Highlands. African Crop Science Journal 5☹2)161-174.

Bayeh M, Stefania G (eds) (2006). Barley research and development in Ethiopia, proceeding of the 2nd National barley research and Development review workshop, Holeta ARC. Ethiopia. ICARDA, PO Box 5466, Aleppo, Syria. pp 391. ISBN 92.

Bekunda M, Bationo A, Ssali H (1997). Soil Fertility Management in Africa: A Review of Selected Research Trials, In Proceedings Replenishing Soil Fertility in Africa. Edrs. pp. 63-79.

Chien SH, Menon RG (1995). Agronomic evaluation of modified phosphate rock products, IFDS's experience, Research and Development Division, International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama 35662, USA.

CIMMYT (1988). From agronomic data to farmer recommendations. An economics-training manual. Completely revised edition. D.F, Mexico. 79.

Central Statistical Agency (CSA) (2016). Agricultural Sample Survey. Crop Land Utilization. Statistical Bulletin No. 171. Addis Ababa, Ethiopia.

Desta B (1987). Effects of liming and nitrogen and phosphorus fertilizers on grain yield of barley, Ethiopian Journal of Agricultural Science 9:1-13.

Ethiopia Soil Information System (EthioSIS) (2014). Ethiopian Agricultural Transformation Agency. Available at: http://www.ata.gov.et/projects/ethiopian-soil-information-system ethiosis/. Accessed on 22 June 2018.

Food and Agriculture Organization (FAO) (2000). Fertilizers and their use: A pocket guide for extension officer. 4th edition, revised, published by FAO and IFA.

Foy CD, Flaming AL (1978). The physiology of plant tolerance to excess available aluminum and manganese in acid soil. In crop tolerance to suboptimal condition. Madison, WI Am. Soc. of Agronomy. Annual Review of Plant Physiology 29:511-566.

Getachew A, Taye B (2005). On-farm integrated soil fertility management in wheat on Nitisols of Central Ethiopian highlands. Ethiopian Journal of Natural Resources 7(2):141-155.

Gomez A (1984). Statistical procedure for agricultural research. 2nd Edn. An international rice institute John Wiley and Sons, Inc. NY, USA.

Hailu B, Muwangi W, Werkneh N (1991). Wheat production constraints in Ethiopia. pp 17-32, In: Hailu Geberemariam, D.G. Tanner and Mengistu Huluka (eds.). Wheat Research in Ethiopia. A Historical Perspective. CIMMYT/IAR, Addis Ababa, Ethiopia.

Hammond LL, Chien SH, Mokwunye AU (1986). Agronomic value of un-acidulated and partially acidulated phosphate rocks indigenous to the tropics. Advances in Agronomy 40:89-140.

Havlin JL (1999). Soil fertility and fertilizer: An introduction to nutrient management, Prentice Hall, Upper Saddle River, New Jersey.

Haynes RJ, Ludecke TE (1984). Yield root morphology and chemical composition of two pasture legumes as affected by lime and p application to an acid soil. Plant and soil 62(2):241-254.

International Food Program Research Institute (IFPRI) (2010). Fertilizer and Soil Fertility Potential in Ethiopia: Constraints and opportunities for enhancing the system.

Kamprath EJ (1984). Crop response to liming in tropics. In soil acidity and liming, pp. 349 -368, (Ed F. Adams). Madison Wisconsin: ASA.

Kumar M, Hazarika S (2012). Liming and Integrated Nutrient Management for Enhancing Maize Productivity on Acidic Soils of Northeast India. Indian Journal of Hill Farming 25(1):35-37.

Meng C, Xiaonan L. (2004). Long term effect of lime application on soil acidity and crop yield on acid soil in central Zhejiang, plant and soil. 265(1):101-109.

Mengel K, Kirkby EA (1987). Principles of plant nutrition, international potash institute, Berne, Switzerland pp. 687-695.

Mesfin A (1998). Nature and Management of Ethiopian Soils. Alemaya University of Agriculture, Ethiopia P 272.

MoFED (2005). Survey of the Ethiopian Economy II, Review of

Developments (1998/99 - 2003/04). Addis Ababa, Ethiopia.
Morel JL, Fardeau JC, Beruff MA, Guckert A (1989). Phosphate fixing capacity of soils: a survey using the isotopic exchange technique of soils from north-eastern France. Fertilizer research 19(2):103-111.
Rajan SS (1987). Partially acidulated phosphate rock as fertilizer and dissolution in soil of the residual rock phosphate. New Zealand journal of experimental agriculture, 15(2):177-184.
Sahlemedhin S, Ahmed A (1983). Phosphorus sorption characteristics of some Ethiopian soils. Ethiopian Journal of Agricultural Sciences 5:1-13.
Sandana P (2016). Phosphorus uptake and utilization efficiency in response to potato genotype and phosphorus availability mean temperature (°C) precipitation (mm) Months. European Journal of Agronomy 76:95-106.
Sarkar D, Haldar A (2005). Physical and chemical methods in soil analysis; fundamental concepts of analytical chemistry and instrumental techniques. National Bureau of Soil Survey and Land Use Planning (ICAR). New Age International (P) Ltd., New Delhi, India.
Scherr S, Yadav S (1996). Land Degradation in the Developing World: Implications for Food, Agriculture, and the Environment to 2020. Food, Agriculture and the Environment Discussion Paper 14. IFPRI, Washington D.C.
Shiferaw B, Anteneh F (2014). Lime and NPK effects on soil acidity and yield of barley in different acid soils of southern region, Ethiopia. International Journal of Natural Sciences 2(7):113-122.
Szilas CJ, Semoka MR, Borggaard OK (2006). Can local Mijingu phosphate rock replace supper phosphate on acid soil in Tanzania. Nutrient Cycling in Agroecosystems 77(3):257-268.
Temesgen D, Alemu G, Adella A, Debele T (2016). Effect of Lime and P fertilizer on Acid soil Barley Performance in the central highlands of Ethiopia. Experimental Agriculture 53(3):432-444.