academicJournals

Vol. 12(7), pp. 467-476, 16 February, 2017
DOI: 10.5897/AJAR2016.11430
Article Number: 5943BBB62760
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Response of phosphorous fertilizer and its recommendation for food barley (*Hordium vulgare* L.) production on Nitisols of central Ethiopian highlands

**Legesse Admassu**

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

Received 13 July, 2016; Accepted 28 September, 2016

**Nowadays, making available proper and balanced fertilizer recommendations is of paramount importance in order to confirm security and increase crop productivity in sustainable way for farmers and other stakeholders. Soil test based phosphorous calibration study was conducted for barley (*Hordium vulgare* L.) on Nitosols of farmers' fields in West Shewa, in the central highlands of Ethiopia. The experiment was arranged in a randomized complete block design with six levels of phosphorous fertilizer (0, 10, 20, 30, 40 and 50 kg ha$^{-1}$) with three replications. Results revealed that yield and yield components of food barley were significantly affected by P fertilizer application. Phosphorous fertilizer application at different rates increased grain yield of food barley by 23 to 46% compared to the control. Available soil test P concentrations analyzed three weeks after planting were affected significantly by P fertilizer application rate. Relative yield and Bray-2 soil test phosphorous value correlation indicated that soil test phosphorous values greater than 13 mg kg$^{-1}$ was found to be sufficient for food barley production. The average phosphorous requirement factor ($P_f$) calculated from soil test phosphorous values of all treatments for study area was 10.2. Most sites tested had Bray 2 P values <10 mg kg$^{-1}$. In the absence of a soil test, a recommendation of 40 kg P ha$^{-1}$, resulting in the best response overall, could be made for the first year of application. It was also recommend that to prevent a potential loss of barley yield, a maintenance application of at least 5 to 10 kg P ha$^{-1}$ be applied every year, irrespective of the calculated recommended rate, in order to replace P exported from the field in the form of grain and straw yield. Further field trials are required to determine interactions between P response and the effects of climate, soil properties, and other management practices.**

**Key words:** Food barley, phosphorous calibration, nitisols, phosphorous requirement factor, critical concentration.

## INTRODUCTION

Soil fertility decline due to continued degradation of agricultural soils is a major concern in African agriculture in general and in Ethiopia in particular. Among the bio-physical factors, it remains to be single most important

E-mail: legesse.admassu@gmail.com.

constraint to food security in sub-Saharan Africa (SSA) (Bekele and Drake, 2003). The International Centre for Soil Fertility and Agricultural Development estimates that Africa loses 8 million metric tons of soil nutrients per year and over 95 million hectare of land have been degraded to the point of greatly reduced productivity (Henao and Baanante, 2006). According to Stoorvogel et al. (1993, the annual average nutrient loss for SSA was 26 kg N, 3 kg P, and 19 kg K ha$^{-1}$ year$^{-1}$ with that for Ethiopia being 47 kg N, 7 kg P and 19 kg K ha$^{-1}$ year$^{-1}$ resulting in a negative nutrient balance (Omotayo and Chukwuka, 2009). In contrast, farms in North America and Europe have averaged net positive nutrient balances (Sanchez et al., 1994). Farmers in SSA seldom apply fertilizers in the recommended fertilizer rates at appropriate time that does not consider the crop nutrient requirement because of many socioeconomic constraints such as lack of supplies, cost of fertilizers, lack of access to financial credit, delivery delays, low and variable returns (Partey and Thevathasan, 2013). With rapid population growth, continuous and intensive cropping without restoration of the soil fertility, has depleted the nutrient base of most soils (Alice et al., 2012) resulting in poor crop yields. Nutrient depletion could be even worse in highly populated countries such as Ethiopia (Haileslassie et al., 2006).

Barley one of the most important food crops predominantly grown from 1500 to 3500 m above sea level in Ethiopia (Lakew et al., 1996). It covers an area of about 1.13 million ha, but its national average yield is low at 1.7 t ha$^{-1}$ (CSA, 2014). Phosphorous (P) is usually the most yield limiting of soil-supplied elements, and soil P tends to decline when soils are used for agriculture (David and David, 2012). A high proportion of the grain becomes human food, and a consequent residue is not returned to the field as often as plant or animal wastes (Buol, 1995). The low solubility of phosphates and their rapid transformation to insoluble forms makes P less available or unavailable to crops (Smil, 2000). P is deficient in about 70% of the soils in Ethiopia (Mamo and Haque, 1991). Barley production in Nitisol areas of Ethiopia are marginally to severely deficient in P and constrained by soil acidity and low nutrient availability (Agegnehu et al., 2011; Regassa and Agegnehu, 2011) making it the main growth limiting factor (David and David, 2012). These highlands constitute 43% of the country but account for 95% of the cultivated area and support 88 and 75% of the human and livestock population, respectively (Yirga and Hassan, 2013)

Sound soil test based and site specific nutrient management is essential in reversing this trend and increase crop yield in agricultural land. It is essential for successful fertilization program and crop production. It is a reliable and accurate method to identify the nutrient rates required to attain a desired level of plant growth and yield. It is important that results of soil tests be calibrated against crop response from applications of the plant nutrients in question (Wortmann et al., 2013). A reliable soil test correlates soil nutrients to plant use, and fertilizer recommendations calibrate tests to field conditions for individual crops once relationship between soil test values, fertilizer rates and crop yield is known, it is possible to determine the most economical fertilizer rate for a given crop which can make fertilizer recommendations refined according to the requirements of each field in a given farm (Seif, 2013). Once critical nutrient level and crop requirement are worked out, farmers and producers could use this relatively simple tool to increase fertilizer profitability.

Calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrient to the soil as fertilizer. It provides information how much nutrient should be applied at a particular soil test value to optimize crop growth without excessive waste. Calibration research predicts the probability of response from applying a given nutrient which must be determined experimentally in the field (Dahnke and Olsen, 1990). Calibrations are specific for each crop type, soil type, soil pH, climate plant species, and crop variety (Seif, 2013; Agegnehu and Lakew, 2013; Sonon and Zhang, 2014). Soil testing particularly soil P, tests can be used for evaluating soil P availability and fertilizer recommendations. The reliable nutrient status of farmers' fields' true will only be revealed through chemical soil testing during a particular growing season. The most widely used available soil P test is Bray II (Bray and Kurtz, 1945) on acidic soils (Bado et al., 2008). Instead of simple individual soil tests, soil calibrations of the relationship between soil test and yields of a specific plant are needed for fertilizer recommendation. A critical limit of available P and P requirement factors for a specific soil and crop have been conducted for some crops recently, but the critical limits of available P and P requirement factor are not established for many crops including food barley. Different methods can be used to examine such a relationship. One example of simple graphical method is the Cate Nelson graphical method (Nelson and Anderson, 1977).

The blanket recommendation of 46% P and 64% N for food barley in the central highlands of Ethiopia (Bekele et al., 1993) does not consider the differences in agro-ecological environments (Agegnehu and Lakew, 2013) which may not be applicable under the current production system and for the foreseeable future. Since the spatial and temporal fertility variations in soils were not considered, farmers have been applying same P fertilizer rate to their fields regardless of soil fertility differences. Almost all soil properties exhibit variability as a result of dynamic interactions between natural environmental factors, that is, climate, parent material, vegetation and topography (Jenny, 1941). Soil properties and in turn plant growth are significantly controlled by variation in landscape attributes including slope, aspect and elevation which influence plant nutrient distribution

(Rezaei and Gilkes, 2005) specially in Ethiopian highlands where the steep and dissected terrain topography make soils susceptible to soil erosion and degradation (Hurni, 1988). For this reasons, the blanket recommendation will make inefficient use of these expensive nutrients which contribute to the depletion of scarce financial resources, increased production costs and potential environmental risks (Tarekegne and Tanner, 2001).

Currently, soil fertility research improvement is geared towards site specific fertilizer recommendation. The establishment of a reliable soil test is able to assist in the determination of P requirements. It involves a correlation to find an extractant for soil nutrients for a laboratory test that will best mine an amount of a nutrient proportional to what a plant extracts (Seif, 2013). This will be followed by a calibration to relate soil test numerical value with field nutrient response in the form of crop yield from the addition of the fertilizer nutrient to the soil (Shaver, 2014). Therefore, the objectives of this study were to correlate the Bray-2 soil test P with relative grain yield response of food barley across selected Nitisol areas of West Shewa to establish preliminary agronomic interpretations, and determine the critical P concentration and P requirement factor.

## MATERIALS AND METHODS

### Experimental site

Phosphorous response trials with food barley were conducted on farmers' fields from 2012 to 2015 during the main cropping seasons in West Shewa in the central highlands of Ethiopia. Food barley is grown mainly by subsistence farmers in the highlands of the country. The rainfall is bimodal with long-term average annual rainfall 1100mm, about 25% of which falls from June to September and the rest from January to May and average minimum and maximum air temperature of 6.2 and 22.1°C, respectively. The environment is seasonally humid and major soil type of the trial sites is Eutric Nitisol (FAO classification).

For the selection of representative trial sites across the area over 600 soil samples (0 to 20 cm depth) were collected in three years from farmers' fields before the onset of the trial. Soil samples were analyzed for pH using in a ratio of 2.5 ml of water to 1 g soil available P using Bray II method (Bray and Kurz, 1945) organic C content using Walkley and Black method (1954), total N using Jehldahl method (Bremner and Mulvaney, 1982), exchangeable cations and cation exchange capacity (CEC) using ammonium acetate method (Chapman, 1965). The available soil P (using Bray-2 method) ranges prior to planting considered for classification were <10 mg kg$^{-1}$ for low, 10 to 25 mg P kg$^{-1}$ for medium and >25 for high (Table 1). Based on this categorization 9 farmers with low and medium fields available P were selected for the first year, 5 farmers for the second year and 4 farmers with the same categories for the last two years, respectively.

### Experimental setup

The experiment was arranged in a randomized complete block design with six levels of phosphorous (0, 10, 20, 30, 40 and 50 kg P ha$^{-1}$) with three replications. The plot size was 4 m by 5 m (20 m$^2$) and the spacing between plots and blocks were 0.5 m and 1 m, respectively. The harvested plot size was 16 m$^2$. Barley (*var. HB-1307)* was seeded at the recommended rate of 125 kg ha$^{-1}$. The experiment was planted in June. The sources of N and P were urea and triple super phosphate (TSP), respectively. The P fertilizer was applied at planting. While the recommended N fertilizer (60 kg ha$^{-1}$) was applied two doses; half at planting and half at tillering stage. Other agronomic practices were applied based on local research recommendations.

The first weeding was done 30 to 35 days after planting and the second weeding was carried out a month after the first weeding. Agronomic parameters collected were grain yield, aboveground total biomass, thousand seed weight, test weight, seed weight (g/100 spikes), spike size and plant height (average of 10 plants). One site in the third year was dropped due to poor crop performance and 18 sites were considered for harvesting, data analysis and interpretation in three years. To estimate total biomass and grain yields the entire plot was harvested at maturity in November. After threshing seeds were cleaned weighed and adjusted at 12% moisture level. Total biomass and grain yields recorded on plot basis were converted to kg ha$^{-1}$ for statistical analysis.

### *Determination of critical P concentration (Pc)*

To correlate relative yield vs. soil test P values and determine critical P concentration, the available P was extracted from the soil samples taken three weeks after planting from each plot of all experimental fields using Bray 2 method and three replications for each treatment.

The Cate-Nelson graphical method (Nelson and Anderson, 1977) was used to determine the critical P value using relative yields and soil test P values obtained from 18 P fertilizer trials conducted at different sites, to assess the relationship between grain yield response to nutrient rates and soil test P values, relative grain yields in percent were calculated as follows:

$$Relative\ yield\ (\%) = \frac{Yield}{maximum\ yield}\ X\ 100 \qquad (1)$$

The scatter diagram of relative yield (Y-axis) versus soil test value (X-axis) was plotted. The range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular lines was drawn to divide the data into four quadrants. The vertical line defines the responsive and non-responsive ranges. The observations in the upper left quadrants overestimate the P fertilizer P requirement while the observations in the lower right quadrant underestimate the fertilizer requirement. The intersecting lines were moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points in the two positive quadrants was at a maximum (or conversely, the number of points in the two negative quadrants was at a minimum). The point where the vertical line crosses the X-axis was defined as optimum critical soil test level (Nelson and Anderson, 1977).

### *Determination of P requirement factor (Pf)*

Phosphorous requirement factor (Pf) is the amount of P in kg needed to raise the soil P by 1 mg kg$^{-1}$. It enables to determine the quantity of P required per hectare to raise the soil test by 1 mg kg$^{-1}$, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level (Nelson and Anderson, 1977). It was calculated using available P values in samples collected from unfertilized and fertilized plots.

**Table 1.** Soil nutrient contents of the trial sites before planting food barley in 2012.

| Farmers names | pH (1:2.5 $H_2O$) | Total N (%) | P (mg kg-1) | K (cmol$_c$ kg$^{-1}$ | Na (Cmol$_c$ kg$^{-1}$) | CEC (Cmol$_c$ kg$^{-1}$) |
|---|---|---|---|---|---|---|
| Lelissa | 4.62 | 0.19 | 5.0 | 0.82 | 0.15 | 16.8 |
| Gadissie | 5.63 | 0.18 | 5.2 | 1.94 | 0.11 | 17.1 |
| Teshome | 5.41 | 0.16 | 6.6 | 1.39 | 0.11 | 19.2 |
| Getu | 5.23 | 0.14 | 9.2 | 4.52 | 0.15 | 19.4 |
| Beyene | 5.01 | 0.15 | 6.8 | 0.56 | 0.11 | 17.2 |
| Aselefech | 5.11 | 0.15 | 6.2 | 0.65 | 0.16 | 16.0 |
| Abera | 6.24 | 0.19 | 7.4 | 1.69 | 0.12 | 31.5 |
| Mekonnen | 5.38 | 0.16 | 14.4 | 0.78 | 0.12 | 26.4 |
| Taffa | 5.32 | 0.20 | 6.2 | 0.61 | 0.13 | 18.4 |
| Gudisa | 5.00 | 0.19 | 8.2 | 0.72 | 0.19 | 21.2 |
| Bekele | 5.51 | 0.14 | 4.6 | 0.68 | 0.15 | 17.1 |
| Bizuayehu | 4.98 | 0.20 | 8.8 | 0.52 | 0.14 | 22.4 |
| Dereje | 6.54 | 0.18 | 9.4 | 0.86 | 0.21 | 26.5 |

CEC: Cation exchange capacity.

Phosphorous requirement factor was expressed as:

$$Pf = \frac{kg\ P\ applied}{\Delta\ soil\ P} \quad (2)$$

Therefore, the rate of P fertilizer to be applied (Pa) was expressed in terms of critical P concentration (Pc), initial soil P value (Pi) and P requirement factor (Pf).

$$Pa = (Pc - Pi)\ X\ Pf \quad (3)$$

### Statistical analysis

The data were subjected to analysis of variance using the procedure of the of SAS statistical package version 9.0 (SAS Institute, 2001). The total variability for each trait was quantified using the following model.

$$Tijk = \mu + Yi + Rj(i) + Pk + PY(ik) + eijk \quad (4)$$

where $T_{ijk}$ is the total observation, µ = grand mean, Yi = effect of the $i^{th}$ year, Rj(i) is the effect of the $j^{th}$ replication (within the $i^{th}$ year), $P_k$ is the of the $k^{th}$ treatment, PY $_{(ik)}$ is the interaction of the $k^{th}$ treatment with $i^{th}$ year and $e_{ijk}$ is the random error. Means for the main effects were compared using the means statement with least significant difference (LSD) test at the 5% level.

## RESULTS

### Weather

The total rainfall amount and precipitation pattern for 2012 was significantly higher compared with long-term average, 2013 and 2014 (Figure 1). The rainfall amounts recorded for July and September were considerably higher in 2012 than in 2013 and 2014. When compared with a 30 year average, rainfall in July was higher by 41 mm in 2012, but lower by 122 and 126 mm in 2013 and 2014, respectively, which entails average moisture received in 2012 was conducive for barley growth and development. Moisture deficiency in July and September critically affects tillering and grain filling, respectively.

### Yield and yield components

The responses of grain yield and yield components of food barley to phosphorus fertilization, year and interaction of year by phosphorous of the combined data of over three years are presented in Table 2. The three cropping year data analysis of variance indicated that grain yield and yield components of food barley were significantly affected by year and P fertilizer. Analysis of variance over three cropping seasons revealed that the year effect was highly significant ($p<0.001$) for grain and yield components of barley (Table 2). The year by P fertilizer rate interaction was not significant for grain yield and yield components of barley. The highest mean grain yield (5050 kg ha$^{-1}$) was obtained in the year 2012 compared to the lowest (2313 kg ha$^{-1}$) recorded in 2014. The maximum total crop biomass, harvest index, thousand seed weight, seed weight, test weight, seed weight, spike length and plant height also recorded in the same cropping season (Tables 3 and 4).

Grain yield, total above ground biomass, harvest index, thousand grain weight, test weight, seed weight per spike and plant height of food barley significantly responded ($p<0.01$ and $p<0.001$) to P fertilizer application rate (Table 2). Spike size and moisture content were significantly affected by year only but not by P ($p<0.05$) for grain yield and yield components (Table 2). Grain yield significantly ($p<0.001$) affected by P rate.

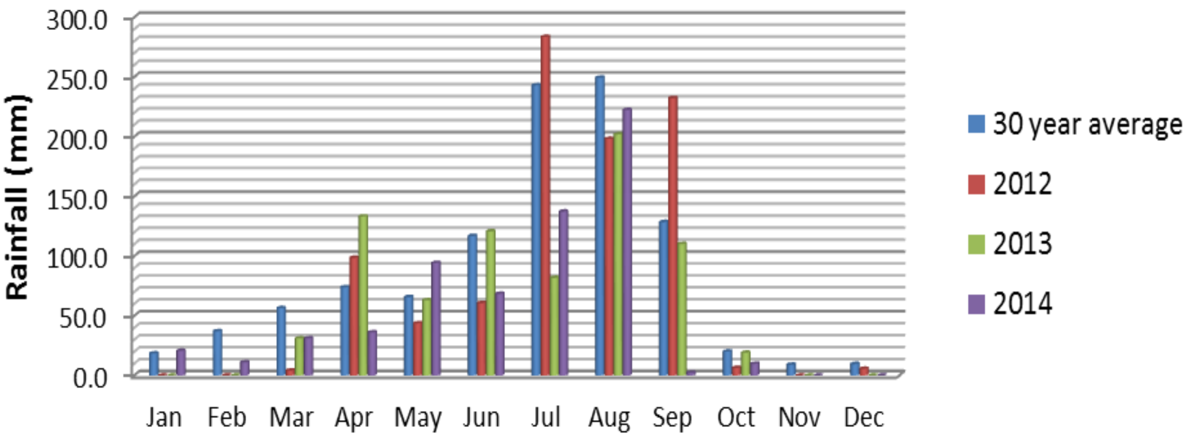

**Figure 1.** Monthly total rainfall for 30 year average, 2012, 2013 and 2014 cropping season's rainfall at Holeta and around the trial sites.

**Table 2.** Effects of year, P fertilizer rate and their interaction on yield and yield components of food barley across sites in 2012, 2013, and 2014.

| Parameter | Year (Y) | Phosphorous (P) | Y×P |
|---|---|---|---|
| Grain yield | *** | *** | ns |
| Total biomass | *** | *** | ns |
| Harvest index | *** | *** | ns |
| Thousand seed weight | *** | *** | ns |
| Seed weight | *** | ** | ns |
| Test weight | *** | ns | ns |
| Spike size | *** | *** | ns |
| Plant height | *** | *** | ns |
| Moisture content | *** | ns | ns |

Significant at **P ≤ 0.01, ***P ≤ 0.001; ns, not significant.

**Table 3.** Table of means for main effects of P application year and fertilizer rate on food barley crop parameters in 2012, 2013 and 2014.

| Factor | Grain yield (kg/ha) | Biomass yield (kg/ha) | Harvest index (%) | Thousand seed weight (g) | Test weight (kg L$^{-1}$) |
|---|---|---|---|---|---|
| **Year** | | | | | |
| 2012 | 5050$^{a}$ | 10536$^{a}$ | 48.1$^{a}$ | 45.3$^{a}$ | 65.2$^{a}$ |
| 2013 | 2505$^{b}$ | 6004$^{b}$ | 42.0$^{b}$ | 42.6$^{b}$ | 62.6$^{b}$ |
| 2014 | 2313$^{b}$ | 6293$^{b}$ | 36.5$^{c}$ | 40.6$^{c}$ | 63.0$^{b}$ |
| | | | | | |
| **Phosphorous** | | | | | |
| 0 | 2923$^{c}$ | 7149$^{c}$ | 40.2$^{c}$ | 40.8$^{c}$ | 63.6 |
| 10 | 3551$^{b}$ | 8113$^{b}$ | 43.1$^{b}$ | 41.8$^{c}$ | 64.1 |
| 20 | 3636$^{b}$ | 8158$^{b}$ | 43.6$^{ab}$ | 41.5$^{c}$ | 64.0 |
| 30 | 3788$^{b}$ | 8408$^{b}$ | 44.1$^{ab}$ | 43.6$^{b}$ | 64.3 |
| 40 | 4268$^{a}$ | 9120$^{a}$ | 45.6$^{a}$ | 46.4$^{a}$ | 64.0 |
| 50 | 4168$^{a}$ | 9166$^{a}$ | 44.4$^{ab}$ | 46.2$^{a}$ | 64.2 |
| CV | 18.3 | 18.6 | 10.6 | 6.2 | 2.8 |
| $P_{linear}$ | *** | *** | ** | *** | ns |

Within each column, means with different letters are significantly different at $p < 0.05$; CV, coefficient of variation

**Table 4.** Table of means for main effects of P application year and fertilizer rate on food barley crop parameters in 2012, 2013 and 2014.

| Factor<br>Year | Seed weight (g/100 spikes) | Spike length (cm) | Plant height (cm) | Moisture content (%) |
|---|---|---|---|---|
| 2012 | $156.0^{a}$ | $6.9^{a}$ | $102.9^{a}$ | 10.9 |
| 2013 | $141.4^{b}$ | $6.4^{b}$ | $95.4^{c}$ | 9.8 |
| 2014 | $126.3^{c}$ | $6.3^{b}$ | $100.4^{b}$ | 10.3 |
| **Phosphorous** | | | | |
| 0 | $138.5^{c}$ | $6.3^{c}$ | $96.7^{d}$ | 10.5 |
| 10 | $141.3^{bc}$ | $6.5^{bc}$ | $99.8^{c}$ | 10.5 |
| 20 | $142.4^{bc}$ | $6.4^{bc}$ | $100.2^{c}$ | 10.5 |
| 30 | $144.5^{abc}$ | $6.7^{ab}$ | $100.5^{bc}$ | 10.4 |
| 40 | $152.1^{a}$ | $6.8^{a}$ | $102.7^{ab}$ | 10.4 |
| 50 | $147.5^{ab}$ | $6.9^{a}$ | $103.5^{a}$ | 10.4 |
| CV | 13.1 | 7.3 | 5.2 | 3.5 |
| $P_{\text{linear}}$ | ** | *** | *** | ns |

Within each column, means with different letters are significantly different at $p < 0.05$; CV, coefficient of variation.

Significantly a higher grain yield was obtained from the application of 40 kg P ha$^{-1}$. The application of P fertilizer rate of 10, 20, 30, 40, and 50 kg ha$^{-1}$ increased grain yields of food barley by 21, 24, 30, 46 and 43%, respectively, compared to the control (without P fertilizer). Application of P fertilizer consistently increased total biomass (linear, $r^2 = 0.9$), grain yield, harvest index, Plant height, thousand seed weight consistently increased as P rate increased, but showed slight decrease beyond 40 kg ha$^{-1}$. However, statistically significant differences were not obtained among P levels for hectoliter weight and moisture content (Table 3). The combined analysis of variance across all experimental locations signify that barley yield and yield components differed significantly ($P<0.001$) among trial locations (data not shown). Physical observations revealed that heading and flowering stages were earlier and higher plant height was recorded in plots that received P fertilizer compared with untreated plots.

## Critical P concentration (Pc) and P requirement factor (Pf)

Soil P values determined three weeks after planting differed significantly ($P<0.01$) among P levels. The main effect of P fertilizer resulted in mean soil test P values of 8.5 to 17.4 mg kg$^{-1}$. Bray-2 soil test P values below 10 mg kg$^{-1}$ are considered low. The increase in soil P response to P fertilizer application was linear up to 50 kg P ha$^{-1}$. The highest mean soil P concentration (17.4) was recorded from 50 kg P ha$^{-1}$ (Figure 2).

The correlation between relative food barley grain yield response and soil P measured with Bray-2 method is indicated in Figure 3. The critical P concentration ($P_c$) was determined from the scatter diagram drawn using relative grain yields of food barley and the subsequent soil test P values for all P levels (0 to 50 kg P ha$^{-1}$). The Pc defined by the Cate Nelson method in this study was about 13 mg P kg$^{-1}$, with mean relative yield response of about 80% (Figure 3). When the soil test value is below the critical value additional information is needed on the quantity of P required to elevate the soil P to the required level. This is the P requirement factor ($P_f$), the amount of P required to raise the soil test P level by 1mg kg$^{-1}$, computed from the difference between available soil test P values from plots that received 0 to 50 kg P ha$^{-1}$ using the second formula mentioned above. Accordingly the calculated Pf were 8.5 to 13 and the overall average $P_f$ of all treatments for the study area was 10.2 (Table 5). Thus the rate of P fertilizer required per hectare can be calculated using the soil critical P concentration, initial soil P determined for each site before planting (Table 1) and the P requirement factor as indicated above in the third formula.

## DISCUSSION

Cropping season disparity has brought about significant differences in yield and yield components. Results have indicated that the amount of seasonal rainfall received and in the growing season greatly impacts the response to P fertilizer application in increasing productivity of food barley. In 2013 and 2014, lower yield and yield components were recorded due to early insufficient amount of rainfall in all trial sites during the tillering period in the month of July. The yield obtained was lower in

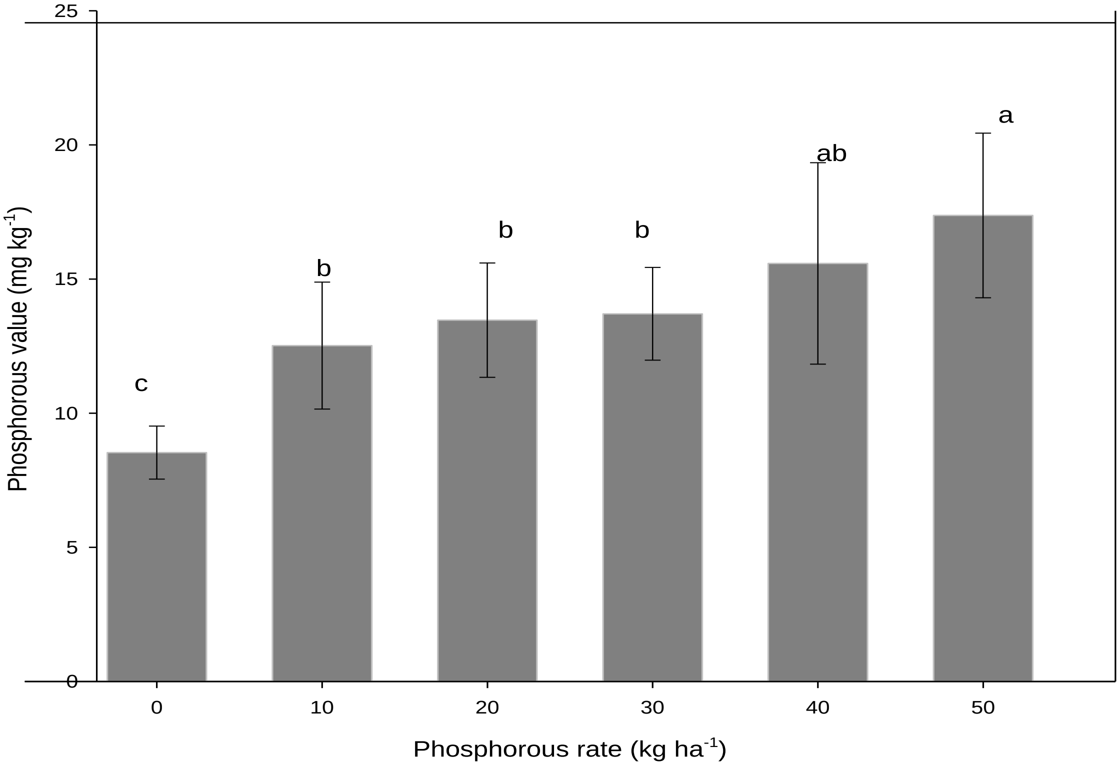

**Figure 2.** Effect of available soil test phosphorous value analyzed three weeks after planting to P fertilizer rate in 2012, 2013 and 2014. Error bars with standard error.

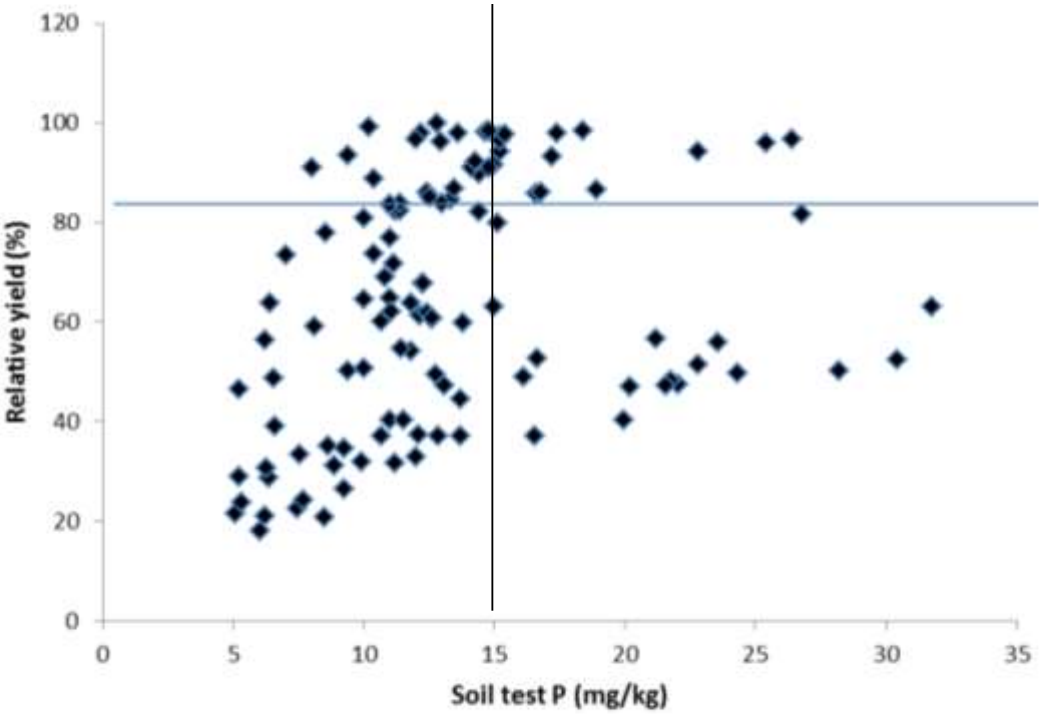

**Figure 3.** Relationships between soil extractable P measured using Bray-2 method and food barley relative yield (percentage of the maximum yield). Using the graphical method of Nelson and Anderson (1977), a critical limit of 13 mg P kg$^{-1}$ of soil extractable P was identified.

**Table 5.** Determination of P requirement factor for food barley on Nitisols in 2012, 2013 and 2014.

| Phosphorous rate (kg/ha) | Soil test P (Bray-II) | | P increase over control | P requirement factor (Pf) |
|---|---|---|---|---|
| | Range | Average | | |
| 0 | 6.4-29.9 | 11.3 | | |
| 10 | 7.0-28.2 | 12.5 | 1.2 | 8.5 |
| 20 | 6.6-27.9 | 13.3 | 2.0 | 9.8 |
| 30 | 7.2-24.3 | 13.6 | 2.3 | 13.0 |
| 40 | 6.6-30.4 | 15.3 | 4.0 | 9.9 |
| 50 | 7.1-31.8 | 16.4 | 5.1 | 9.8 |
| Average | - | - | - | 10.2 |

2014 compared to 2013 because the amount of moisture received in September 2014 was lower during the critical period of grain filling stage. The amount of precipitation received in July 2013 and 2014 was half and one third of the precipitation received in 2012, respectively.

Studies have indicated that grain yield and nutrient uptake of barley were greater in a relatively wetter season than the drier ones (Agegnehu et al., 2006). According to Jones et al. (2011) low nutrient uptake early in a plant's growth lowers nutrient quantity for the seed affecting yield. Crop uptake of nutrients is affected by soil and climatic conditions. One of the constraints is low soil moisture that restrict uptake of plant nutrients. This indicates that a successful soil test fertilizer program is reliant on rainfall and soil moisture status which influences the response of crops and yield to a greater extent than fertilizer applications.

Many different factors combine to limit the success of any soil test and the suitability of the recommendation for a given situation. Food security in Ethiopia is strongly dependent on rainfall variability and soil management practices. Below average seasonal rainfall, little or no rainfall (dry spells), persistent moisture deficit l, severe soil erosion and runoff loss of water and the resultant low soil fertility are the prominent causes for the low agricultural productivity in the Ethiopian highlands. Moreover, the continuous removal of crop residues coupled with minimal use of farmyard manure results in the mining of nutrients, organic matter depletion and weakening of soil structure (Tulema et al., 2007). These processes lead to increased runoff and erosion losses that are strongly linked to topsoil. Therefore, the practice of judicial water conservation undoubtedly plays a significant role in increasing agricultural production in the sub-humid areas where agriculture is hampered by periodic droughts and low soil fertility (Oicha et al., 2010).

Analysis of variance revealed that phosphorous had a highly significant effect on yield and yield component of food barley. Grain yield consistently increased as the rate of P increased up to 40 kg P ha$^{-1}$ then a slight decrease in yield was observed at the highest rate 50 kg P ha$^{-1}$ (Table 3). This could be due to low pH or the lower amount of nitrogen (N) applied at a rate of 60 kg N ha$^{-1}$ alike to all plots. Agegnehu and Lakew (2013) revealed that application of P significantly increased the grain yield of malting barley.

According to the Nelson and Anderson method, the critical level of Bray-2 P in the top 15 cm of soil was about 13 mg kg$^{-1}$. At values of greater than or equal to 13 mg kg$^{-1}$, the crop achieved about 80% of its maximal yield in the absence of P fertilizer application (Figure 3). This implies that P fertilizer application could be recommended for a buildup of the soil P to this critical value, or maintaining the soil P at this level. Increasing P beyond this level, the cost of additional P fertilizer to produce extra yield would likely be greater than the value of the additional yield. Thus the soils with available P status below 13 mg kg$^{-1}$, yield of food barley could show a significant response to applications of P fertilizers. Whereas in areas with available P status greater than 13 mg kg$^{-1}$, the P concentration in the soil exceeds crop needs so that further addition of P fertilizer may not result in a profitable yield increase. Agegnehu and Lakew (2013) reported that Critical concentration of 12 mg P ha$^{-1}$ for malting barley using Bray II test.

According to the result of our study, some yield responsive sites to P fertilizer applications had soil test levels above the critical level. Hence, to protect potential loss of food barley, at least a maintenance application of 10 kg P ha$^{-1}$ may be required depending on the grain yield goal and profitability.

Following the pre-planting of soil analysis results all of the trial sites had lower soil P values than the critical P concentration. This had a direct relationship with the crop growth and yields. In most cases, soil pH less than 5.5 is deficient in available P and exchangeable cations (Brady and Weil, 2010). In such soils the proportion of P fertilizer that could be available to a crop becomes inadequate (Brady and Weil, 2010), unless amended through organic matter maintenance or liming to increase soil pH between 6.5 and 7 (Wortmann, 2015) for acid neutralization and applied through proper placement to increase the efficiency of utilization of the applied fertilizer. Higher coefficient variability in grain yield of food barley on Nitisols may have been related to greater variability within and among less fertile sites.

## Conclusion

Soil-test P fertilizer calibration for food barley on Nitisols was proposed based on the Bray 2 extraction. This calibration is based on the analysis of six different P-rate test sites in which crop response to P fertilizer was determined in three cropping seasons (years). The results of this field work clearly indicated the importance of soil test based P fertilizer application on achieving maximum yield and yield components of food barley under field conditions of West Shewa on Nitisols soil type. In this part of the country, soil fertility depletion is severe and use of external input is very low. The critical available soil P concentration (13 mg kg$^{-1}$) in Bray -2 method and the average P requirement factor (10.2) on Nitisols have been established for the study sites and similar areas. The results seem promising and could be used as a basis for soil test P fertilizer recommendations for the production of food barley on Nitisols areas of central Ethiopian highlands. They can also be used for future intensification in the other areas for developing a system for soil test based fertilizer recommendation. Nevertheless, to develop an effective guideline for wider applicability of soil test based fertilizer recommendations, additional research assisted by appropriate soil P extraction method is required to generate sufficient information for the most important crop-soil systems.

## CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The authors are grateful to Chanyalew Mandefro, Beyene Ofa, Haile Biza, Kasech Berhanu, the Barley Improvement Research Team and Holeta Research Center Soil and Plant Analysis Laboratory for their technical assistance. The Ethiopian Institute of Agricultural Research is acknowledged for funding the experiment.

## REFERENCES

Agegnehu G, Lakew B (2013). Soil test phosphorous calibration for malting barley (*Hordium vulgare* L.) production on Nitisols of Ethiopian highlands. Trop. Agric. 90:177-187.

Agegnehu G, Liben M, Molla A, Feyisa A, Bekele A, Getaneh F (2011). “Research achievements in soil fertility management in relation to barely in Ethiopia.” In Barley research and development in Ethiopia edited by B. Mulatu and S. Grando, ICARDA, Aleppo, Syria. pp. 137-152.

Agegnehu G, Ghizaw A, Sinebo W (2006). Yield performance and land use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. Eur. J. Agron. 25:202-207.

Alice AS, Masateru M, Kengo I (2012). Effects of Soil Fertility Management on Growth, Yield, and Water-Use Efficiency of Maize (*Zea mays* L.) and Selected Soil Properties. Commun. Soil Sci. Plant Anal. 43(6):924-935.

Bado BV, DeVries ME, Haefele SM, Marco MC, Ndiaye MK (2008). Critical limit of extractable phosphorous in a Gleysol for rice production in the Senegal River valley of West Africa. Commun. Soil Sci. Plant Anal. 39:202-206.

Bekele W, Drake L (2003). Soil and water conservation behavior of subsistence farmers in the Eastern highlands of Ethiopia: A case study of the Hunde lafto area. Ecol. Econ. 46:437-451.

Bekele T, Ashagre A, Tulema B, GebreKidan G (1993). Soil fertility management in Barley. In: Barley research in Ethiopia: past work and future prospects. Proceedings of the first barley research review workshop.16-19 October 1993, Addis Ababa: IAR/ICARDA. Addis Ababa, Ethiopia.

Brady NC, Weil RR (2010). Elements of the nature and properties of soils. Pearson Education International. New Jersey.

Bray RH, Kurz LT (1945). Determination of total, organic, and available forms of phosphate in soil. Soil Sci. 59:39-45.

Bremner JM, Mulvaney CS (1982). Nitrogen total. In Methods of soil analysis, ed. A. L. Madison, WI: American Society of Agronomy, SSSA. pp. 595-624.

Buol SW (1995). Sustainability of soil use. Ann. Rev. Ecol. Syst. 26(1):5-44.

Chapman DD (1965). Determination of exchangeable Ca, Mg, K, Na, Mn, and effective cation exchange capacity in soil. In Methods of soil analysis, ed. C. A. Black, Madison, WI: ASA, SSSA. pp. 902-904.

Central Statistical Agency (CSA) (2014). Area and production of major crops for 2013/2014 Meher (main rainy) season for private peasant holdings in Ethiopia. Statistical bulletin. Addis Ababa.

David ME, David JT (2012). Modeling an Improvement in Phosphorus Utilization in Tropical Agriculture. J. Sust. Agric. 36(1):18-35.

Dahnke WC, Olsen RA (1990). Soil test correlation, calibration, and recommendation. P 45-71. In: R.L. Westerman (ed.) soil testing and plant analysis, 3rd ed., Soil science society of America, Madison, WI. SSSA Book Series: 3.

Haileslassie A, Priess JA, Veldkamp E, Lesschen JP (2006). Smallholders’ soil fertility management in the central highlands of Ethiopia: Implications for nutrient stocks, balances and sustainability of agroecosystems. Nutr. Cycl. Agroecosyst. 75:135-146.

Henao J, Baanante C (2006). Agricultural production and soil nutrient mining in Africa: Implication for resource conservation and policy development. IFDC Tech. Bull. International Fertilizer Development Center. Muscle Shoals, Al. USA.

Hurni H (1988). Degradation and conservation of the resources in the Ethiopian highlands. Mt. Res. Dev. 8:123-130.

Jenny H (1941). Factors of soil formation: a system of quantitative pedology by Hans Hans Jenny. McGraw-Hill, New York.

Jones C, Olson-Rutz K, Dinkins CP (2011). Nutrient Uptake Timing by Crops: to assist with fertilizing decisions. Montana State University. USA.

Lakew B, Gebre H, Alemayehu F (1996). Barley production and research in Ethiopia. In: Gebre G, van Leur J, editors. Barley research in Ethiopia: past work and future prospects. Addis Ababa: IAR/ICARDA. pp. 1-8.

Mamo T, Haque I (1991). Phosphorous status of some Ethiopian soils.II. Forms of and distribution of inorganic phosphates and their relation to available phosphate. Trop. Agric. 68:2-8.

Nelson LA, Anderson RL (1977). Partitioning soil test–crop response probability. In Soil testing: Correlating and interpreting the analytical results, ed. T. R. Peck. Madison, WI: American Society of Agronomy pp. 19-39.

Oicha T, Cornelis WM, Verplancke H, Nyssen H, Govaerts B, Behailu M, Haile M, Deckers J (2010). Short term effects of conservation agriculture on Vertisols under tef (Eragrostis tef (Zucc.) Trotter) in the Northern Ethiopian highlands. Soil Till. Res. 106:294-302.

Omotayo OE, Chukwuka KS (2009). Soil fertility restoration technique in sub-Saharan Africa using organic resources. Afr. J. Agric. Res. 4:144-150.

Partey ST, Thevathasan NV (2013). Agronomic Potentials of Rarely Used Agro-forestry Species for Smallholder Agriculture in Sub-Saharan Africa: An Exploratory Study. Commun. Soil Sci. Plant Anal. 44(11):1733-1748.

Regassa H, Agegnehu G (2011). “potentials and limitations of acid soils in the highlands of Ethiopia: A review." In Barley research and development in Ethiopia edited by B. Mulatu and S. Grando. ICARDA, Aleppo, Syria pp. 103-112.

Rezaei SA, Gilkes RJ (2005). The effects of landscape attributes and community on soil chemical properties in the rangelands. Geoderma 125:167-176.

Sanchez PA, Woomer PL, Palm CA (1994). Agro-forestry approaches for rehabilitating degraded lands after tropical deforestation. In: Rehabilitation of degraded lands in the tropics: technical approach. JIRCAS International Symposium Series; 1992 Sep. 16-17; Tsukuba Japan. Tsukuba (Japan): Japan Int. Res. Center Agric. Sci. pp. 108-119.

SAS Institute (2001). SAS/STAT User's Guide, Version 8.2. SAS Institute, Cary, NC.

Seif J (2013). Soil testing. Fact sheet No. 0.501. Crop/soil series. Colorado state university. USA.

Shaver TM (2014). Soil testing and Nutrient recommendations. University of Nebrasaka.USA.

Smil V (2000). Phosphorus in the environment: natural flows and human interferences. Ann. Rev. Energy Environ. 25(1):53-88.

Sonon LS, Zhang H (2014). Soil test calibration work in southern USA. University of Texas A and M university. USA.

Tarekegne A, Tanner D (2001). Effects of fertilizer application on N and P uptake, recovery and use efficiency of bread wheat grown on two soil types in central Ethiopia. Ethiop. J. Nat. Res. 3:219-244.

Tulema B, Jens BA, Tor AB (2007). Availability of organic nutrient sources and their effects on yield and nutrient recovery of tef [*Eragrostis tef* (Zucc.) Trotter] and on soil properties. J. Plant Nutr. Soil Sci. 170:543-550.

Walkley A, Black CA (1954). An examination of the Degtjareff methods for determining soil Organic matter and proposed modification of the chromic acid titration methods. Madison, WI: ASA and SSSA.

Wortmann CS (2015). Principles of Fertility. nutrient management for agronomic crops in Nebraska. University of Nebraska–Lincoln Extension, Lincoln, NE. P 17.

Wortmann CS, Helmers M, Malarino A, Barden C, Devlin D, Pierensky G, Lory J, Massey R, Holz J, Shapiro C, Kovar J (2013). Agricultural phosphorous management and water quality protection in the mid west. Research publication Research publication RP187, Revised.
University of Nebraska-Lincoln Extension, Lincoln, NE.

Yirga C, Hassan RM (2013). Determinants of inorganic fertilizer use in the mixed crop livestock farming systems of central highlands of Ethiopia. Afr. Crop Sci. J. 21:669-668.