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Maize (*Zea mays* L.) crop response to phosphorus fertilization on fluvisols in Northern Ethiopia

Fisseha Hadgu[1*], Heluf Gebrekidan[1], Kibebew Kibret[1], BirruYitaferu[2]

[1]*School of Natural Resources Management and Environmental Sciences, Haramaya University, Ethiopia*

[3]*Amhara Regional Agricultural Research Institute, Amhara National Regional State, Ethiopia*

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Abstract

A field experiment involving different P fertilizer rates (0, 10, 20, 30, 40, 50 and 60 kg P ha^{-1}) was conducted to determine effect of P on maize (*Zea mays* L.) growth, yield, N and P uptakes and P use efficiency on Fluvisols at Birki village, northern Ethiopia using a randomized complete block design with three replications. The experiment was conducted under rain-fed condition between 10 July and 12 November 2011. Application of 30 kg P ha^{-1} significantly ($P \leq 0.01$) increased maize grain yield, total above ground N and P uptakes, grain N and P uptakes and P harvest index. At this P level, grain yield increased by 1074 kg ha^{-1} (54.8%) over the control plot. Soil P at harvest has also significantly ($P \leq 0.01$) increased as applied P increased from 0 to 60 kg P ha^{-1}. Significant ($P \leq 0.05$) increments were also observed on plant height, maize ear length and total above ground dry matter weight at 40 kg P ha^{-1} and on shoot P uptake at 30 kg P ha^{-1}over the control. However, no significant ($P > 0.05$) differences were observed on shoot dry matter weight, number of grains per ear, harvest index and shoot N uptake. Phosphorus use efficiencies of maize were also observed to decrease with increasing levels of applied P. At the optimum application rate of 30 kg P ha^{-1}, observed P agronomic and P utilization efficiencies of maize were 28.7 and 32.1 kg kg^{-1}, respectively. Generally, the results of the study indicated that application of P fertilizer significantly increased the grain yield of maize mainly through its positive effects on the crop‘s growth parameters, yield components and total plant N and P uptakes. The analysis of marginal rate of return has further confirmed that application of 30 kg P ha^{-1} gave the highest net return of 3717.4 Birr ($203) ha^{-1}which implies that it can be recommended for the production of economically optimal maize yield on Fluvisols under the environment prevailing in the study areas.

*Corresponding Author: Fisseha Hadgu ✉ habenfhb@gmail.com

Introduction

Of the major nutrients, the world phosphorus (P) resource is the smallest and on a global scale, P should be used as efficiently as possible in order to conserve the resource. Soils containing insufficient amounts of plant-available P not only produce economically unacceptable yields, but other inputs, particularly nitrogen (N), are also used less effectively (Ibrahim and Kandil, 2007; Hussaini *et al.*, 2008). Thus, there is an urgent need to seek strategies by which P fertilizers can be used more effectively in the farming systems where P is currently deficient and where its use is economically feasible.

Moreover, there is a need to increase the use of P fertilizers in Ethiopia in order to ensure food security for its growing population. According to Girmay (2006), two of the major constraints of agricultural production in Tigray National Regional State (TNRS) are high level of erosion and poor fertility of the soils. The soils in the Region are among others extremely deficient in available P. According to the Bureau of Planning and Economic Development (BOPED, unpublished document) of Tigray, average cereal crop productivity in the TNRS is about 0.8 tons per hectare (t ha^{-1}).

Various factors, including the form of native soil P and soil reaction determine the availability of P to crop plants (Sarhadi-Sardoui *et al.*, 2003). Phosphorus is absorbed by clay colloids, carbonates and Fe-oxides. Following its application to the soil, P reacts immediately with soil particles and converts to less available forms by the processes of adsorption and precipitation (Chaudhary *et al.*, 2003). Fertilizer P applied to the soils undergoes transformations. These processes that convert P into unavailable form contribute to its less use efficiency. Most of the P applied to soil can be converted into unavailable forms that cannot be easily utilized by plants. Differences in phosphorus utilization efficiency may also occur among plant species (Kizilgoz and Sakin, 2010) or genotypes (Kogbe and Adediran, 2003; Tehseen, 2005) of the same species due to differences in amounts of shoot dry matter produced per unit of P acquired (Fageria, 2009). This may be related to the ability of plants to translocate and use inorganic P in their tissues. It has been reported by many workers that maize crop responds very well to P fertilizer and thus increase grain yield. The importance of P as yield limiting factor for many crops in many Ethiopian soils is also well established. Nutrient use efficiency is, hence, receiving a great deal of attention today because of the increasing fertilizer costs associated with natural gas costs and growing pressure for agriculture to minimize negative environmental impacts (Fixen, 2004). Managing P sources, including fertilizers, is one of the possible options for improving the efficiency of soil and fertilizer P use (FAO, 2008; Wasonga *et al.*, 2008).

Maize is one of the most important cereal crops in the world (Onasanya *et al.*, 2009). It ranks third in the world surpassed only by wheat and rice. Similarly, maize is among the major crops grown by farmers in Ethiopia which is used for food and for preparation of local beverages. It is also one of the major food crops in TNRS (BOPED, 2004) and is among the three major crops (maize, wheat and teff) grown by farmers in the specific study district. Besides, it is the most dominant cereal crop grown during the off-season by irrigation in the area. Preliminary assessment revealed that *Katumani* variety of maize is adopted by majority of farmers in the study area.

Phosphorus plays an important role in many processes that occur in maize plant. It affects the quality of the grains and may increase the crop's resistance to diseases. It is also essential for good vegetative growth and grain development in maize. However, the requirement and utilization of P in maize depends on environmental factors like rainfall, soil type, varieties and expected yield (Onasanya *et al.*, 2009). Phosphorus deficiency in many soils is largely due to low occurrence of P-containing minerals and P fixation (Van der Eijk, 1997). Continuous cropping without nutrient replenishment practices is also reported to contribute to low P content of many soils (Smaling *et al*., 1997; Sanchez, 2002; FAO, 2004). This scenario is also common in most soils of northern Ethiopia where the smallholder farmers continuously grow the crop without application of adequate nutrient sources for centuries. Although smallholder farmers in TNRS (northern Ethiopia) grow the crop, its production is constrained by low soil P (HTSL, 1975). The Fluvisols in TNRS in particular and in Ethiopia in general which are alluvial soils alongside rivers are important because of their position in the landscape for irrigation. However, they are not utilized to their production potential because of many constraints among which nutrient management problems are common. Available P has been found to be low in the Fluvisols of the Mesanu Tabia (HTSL, 1976) which is located in TNRS, northern Ethiopia and represents the specific site of the present study. These soils are mainly cultivated for vegetables and cereals, mainly maize during both the main and off-seasons.

Farmers in Mesanu Tabia use the blanket P fertilizer recommendation which was based on pilot studies in other areas and which are different in agro-ecology, soil type, crop type and variety to the condition in the study area. Besides, the utilization efficiency of applied P is not known. Therefore, the introduced and adopted maize varieties which are continually being grown by farmers call for the need to determine their P requirement. Changes in soil P levels with continued cultivation also necessitate the reassessment of fertilizer P application rates. Hence, this paper examines the effect of P application on the yield, N and P uptakes and P use efficiency of *Katumani* maize variety on Fluvisols in Mesanu Tabia of northern Ethiopia.

Materials and methods

Description of the experimental site

The experiment was conducted from 10 July to 12 November 2011 at farmers training center field of Birki village in Mesanu Tabia, located in Kilte-Awlae'lo District, eastern zone of Tigray. It is located at latitude of 13° 42´ N and longitude 39° 39´ E with an altitude of 2065 m above sea level. The village is a semi-arid area characterized by a long dry season with a main rainy season between June and September. It is 8 km east of Agulae village which is about 25 km north east of Mekelle city, the capital of Tigray Region.

The mean annual rainfall of the site was 590 mm. The maximum and minimum temperatures for the District of Wukro in eastern Tigray (the nearest place with meteorological station for Birki village) for the years 1963 to 1997 range from 23-28 and from 9-14 °C, respectively (National Meteorological Service Agency, Wukro Sation).

The population of Mesanu Tabia is 6245. Topography of Mesanu Tabia is mainly the extension of the central highland of Ethiopia which comprises of highlands. Mesanu Tabia has 9454.86, 1325.87 and 609.9 ha, total, cultivated and irrigated area, respectively (personal communication). This experiment represents the whole of the valley with similar soil type which covers larger area outside Mesanu Tabia. The soils were classified as highly suitable for dry land or irrigated arable farming (HTSL, 1976). Fluvisols is one of the major soil types in the study area and is derived from alluvium parent material. It is classified as Eutric Fluvisols (HTSL, 1976). The production system is mixed crop-livestock farming and the major food crops cultivated are cereals (mainly maize, wheat and teff), pulses and vegetables.

The farmers of the area use supplementary irrigation when rainfall stops at the end of the main rainy season. Maize is produced in off-season and in the rainy season, twice per year, in the Tabia. Yield of maize varies during the two seasons and the highest yield can reach forty quintal ha^{-1} when farmers use fertilizer, other high yielding varieties and irrigation. However, according to the farmers in the study area, yield for *Katumani* is relatively low but they prefer this variety for its early maturity.

Soil sampling and analysis

Soil sampling and sample preparation

Soil samples were collected from the experimental site at the depth of 0-15 cm before sowing and at the time of harvesting. The composite soil samples for the laboratory analysis were air dried, crushed using pestle and mortar and passed through a 2 mm diameter sieve for analysis of most of the soil chemical properties and for remained P. A portion of the disturbed soil sample was taken and sieved using 0.5 mm diameter sieve for the determinations of organic matter.

One composite sample was prepared from 10 holes at 100 m distances for the laboratory analyses of soil properties, using auger for the sample collected before sowing. Similarly, undisturbed soil samples were collected using core sampler for soil bulk density and water retention at field capacity (FC) and permanent wilting point (PWP) determinations. One composite sample each from the experimental plots was also collected from spots around plants at harvest which were used for analyzing the available P that remained in the soil. The samples were transported to Mekelle for laboratory analysis.

Laboratory analysis of soils

Particle size distribution was determined by the hydrometer method (Day, 1965). Once the sand, silt, and clay separates were calculated in percent, the soil was assigned to a textural class based on the soil textural triangle using International Soil Science Society (ISSS) system (Rowell, 1994). Dry bulk density was determined by the core method (Hesse, 1971). Soil moisture contents were measured using the method outlined by Black (1965). Soil moisture contents at FC and PWP were determined in laboratory by using a pressure plate apparatus to apply suctions of 1/3 and 15 bars, respectively to a saturated soil sample. When no longer water was leaving the soil sample, the soil moisture in the sample was determined gravimetrically and equated to FC and PWP. Volumetric moisture content at FC and PWP was then calculated by multiplying the gravimetric soil moisture content by the bulk density. The differences between FC and PWP were calculated taking the root depth in to consideration to determine the amount of water to be applied by of supplementary irrigation on volumetric basis.

Soil pH in water was determined by the glass electrode pH meter (Peech, 1965) at 1:2.5 soil-water ratios. The electrical conductivity (EC) of the soil was measured according to the method described by Peech (1965). The cation exchange capacity (CEC) was determined using the method described by Chapman (1965). Percent base saturation (PBS) was calculated as the ratio of exchangeable bases (Ca, Mg, K and Na) and CEC. Potassium and Na were determined using flame photometer as described by Rowell (1994), while Ca and Mg were read using atomic absorption spectrophotometer (Hesse, 1971). Calcium carbonate ($CaCO_3$) was determined by titration according to FAO (1974). The total N content in soils was determined using the Kjeldahl procedure by oxidizing the organic matter with sulfuric acid and converting the N into ammonium ion (NH_4^+) as ammonium sulfate (Sahlemedhin and Taye, 2000). Soil available P was analyzed using Olsen method (Olsen *et al.*, 1954) modified by Watanabe and Olsen (1965). To determine organic carbon, the Walkley and Black (1934) method was employed. Finally, the organic matter content of the soil was calculated by multiplying the organic carbon percentage by 1.724.

Field experimental treatments, design and procedure

Treatments and experimental design

An experiment in a randomized complete block design in three replications was laid down in a field condition. Seven rates of P (0, 10, 20, 30, 40, 50 and 60 kg P ha^{-1}) were applied to plots. Phosphorus was applied as triple super phosphate (TSP). Nitrogen at the rate of 46 kg ha^{-1} was uniformly applied at planting as urea to all plots. The amounts of urea and TSP were calculated for each P level for 3 x 4.5 m^2 experimental plots. The amounts of fertilizers for each plot and row were then weighed using sensitive balance and applied at 5 cm below and apart from seed during sowing.

Planting and cultural practices

Maize (*Katumani*) seeds, a widely grown early maturing maize cultivar obtained from Ethiopian seed enterprise were sown on July 10, 2011. Three seeds were planted per hole in rows at spacing of 75 cm x 30 cm and at 5 cm depth. Seedlings were later thinned to one plant per hole. The field border one meter away from the plots was sown by maize seeds. Weeds were controlled by hand weeding to reduce competition for space, water, light and nutrients between the crops and weeds. The plants were cultivated three times using spade for proper aeration. The plants were supported by irrigation when the rain stopped at early September.

Crop data collection

The plants were harvested 12 November at maturity (120 days after sowing. Above-ground portion of 24 plant samples were selected from two middle rows in each plot. Heights of these plant samples were measured before harvesting. A carpenter's tape was used for measuring the height from the ground level to the top-most leaf. The mean from the 24 plants was then calculated. The samples from each plot were separated into stover, leaves, cob, tassel, husk and grains after weighing the whole above-ground part. The different parts were separately dried in an oven at 65 ^oC until the constant weight is attained (Jones and Case, 1990). Dry matter weight data of the above-ground shoot part was then taken. The different parts of the plants were weighed separately and percent of each part out of the above ground total shoot weight was calculated. The grain too was weighed, and moisture content measured using moisture meter and then sub-sampled for dry matter determination. Harvest index was calculated from grain weight and total weight (grain plus shoot weight).

Plant tissue sampling and analysis

The different portions of the above-ground plant samples were chopped into small pieces, mixed and fine ground. They were weighed with sensitive balance and made ready for subsequent total N and P determinations. The shoot and grain samples were wet digested and analyzed for total N, using the Kjeldahl method. Dried shoot and grain samples were dry ashed using furnace at 300 ^oC for five hours and analyzed for P content as for the soil P (Olsen *et al.*, 1954). Nitrogen and P uptakes by grain shoot as well as by total above ground biomass were calculated. Phosphorus index was calculated from grain and total above ground biomass P content.

Phosphorus uptake and use efficiencies

Agronomic efficiency (AE), physiological efficiency (PE), agro-physiological efficiency (APE), recovery efficiency (RE) and utilization efficiency (UE) of P were calculated from the grain biological yields, nutrient uptake values and the applied P fertilizer rates. Accordingly, AE, the economic production obtained per unit of nutrient applied, was calculated as:

$$AE\ (kg\ kg^{-1}) = G_f - G_u/N_a,$$

where G_f is the grain yield of the fertilized plot (kg), G_u is the grain yield of the unfertilized plot (kg), and N_a is the quantity of P applied (kg).

Physiological efficiency, which is the biological yield obtained per unit of nutrient uptake, was calculated as:

$$PE\ (kg\ kg^{-1}) = BY_f - BY_u/N_f - N_u,$$

where BY_f is the biological yield (grain plus shoot) of the fertilized plot (kg), BY_u is the biological yield of the unfertilized plot (kg), N_f is the P uptake (grain plus shoot) of the fertilized plot (kg), and Nu is the P uptake (grain plus shoot) of the unfertilized plot (kg).

APE is defined as the economic production (grain yield in case of annual crops) obtained per unit of nutrient uptake. It was therefore calculated as:

$$APE\ (kg\ kg^{-1}) = G_f-G_u/N_{uf}-N_{uu},$$

where G_f is the grain yield of fertilized plot (kg), G_u is the grain yield of the unfertilized plot (kg), N_{uf} is the P uptake (grain plus shoot) of the fertilized plot (kg), N_{uu} is the P uptake (grain plus shoot) of unfertilized plot (kg).

Apparent recovery efficiency which provides the quantity of nutrient uptake per unit of nutrient applied was calculated as follows:

$$ARE\ (\%) = (N_f - N_u/N_a) \times 100,$$

where N_f is the P uptake (grain plus shoot) of the fertilized plot (kg), Nu is the P uptake (grain plus shoot) of the unfertilized plot (kg), and N_a is the quantity of P applied (kg).
Finally, UE was obtained as the product of the PE and RE):

$$EU\ (kg\ kg^{-1}) = PE \times ARE,$$

as suggested by Fageria and Barbosa (2007).

Data analysis
The crop growth, yield component including nutrient uptake and yield as well as P remained in the soil were subjected to analysis of variance appropriate for RCBD with the help of MSTATC software (Michigan State University, 1991). Duncan's multiple range test was used to separate means for the treatment effects as the number of treatments are many, above six (Gomez and Gomez, 1984). The least significant difference (LSD) values given in the tables in the result and discussion part are Duncan's multiple range test LSD values. The P rate was regressed on grain yields, grain P uptakes and P utilization efficiency. Marginal rate of return (Table 4) was calculated for grain yield to obtain the economically optimum rate of applied P. The prices of P and maize yield were considered at the time of sowing and harvesting, respectively to calculate marginal return.

Results and discussion

Soil properties
The result of laboratory analysis of selected physical and chemical properties of soils of Birki village is presented in Table 1. The textural class of the soil under investigation was sandy loam based on the soil textural triangle of the International Society of Soil Science (ISSS) system (Rowell, 1994). Bulk density was moderate according to Harte (1974). On the basis of $CaCO_3$ rating suggested by Nachtergaele *et al.* (2009), the soil of the study area was moderately calcareous in nature. The soil sample was very low in organic carbon as per rating suggested by Charman and Roper (2007). The data further revealed that the soil sample was moderately alkaline on the basis of pH limit proposed by Bruce and Rayment (1982) On the basis of EC limit purposed by Bruce and Rayment (1982), the soil under investigation falls in the category of non saline soils. The soil has low CEC value, on the basis of CEC rating by Metson (1961), and this might be due to its coarse texture, low organic matter and presence of $CaCO_3$. High exchangeable K, moderate exchangeable Ca and low exchangeable Mg and Na were observed as per the rating by Metson (1961). The PBS calculated from these cations was very high according to rating by Metson (1961). As per the rating set by Bruce and Rayment (1982), soil total N was low. Based on the rating set by Landon (1991), the available phosphorus in the plow layer of the soil was also low (Table 1).

Effect of p on growth of maize
Plant height and maize ear length
The data in Table 2 showed increment in plant height from 0 to 40 kg P ha^{-1} across the treatments at maturity stage of growth (ranging 129.8 to 180.7 cm) and the increment decreased at the next higher P treatments. However, the differences over the control treatment were significant ($P \leq 0.05$) only at the applied P rates of 30 and.40 kg P ha-1. The minimum plant height was recorded in the control plot as compared to the plant height recorded in the other treatments (Table 2). The significant differences observed in maize plant height may be attributed to P. (Table 2). Similar results were also reported by Ibrahim and Kandil (2007) in Egypt.

Increasing trend was observed on ear length showing significant ($P \leq 0.05$) difference at the rate of 40 kg P ha^{-1}due to P application. Ear length ranged from 12.45 to 15.61 cm at the rates from 0 kg P to 40 kg P ha^{-1} then after decreased (Table 2).

Table 1. Physical and chemical properties of Fluvisols in Birki village, northern Ethiopia

Soil properties	Value
Sand (%)	71.0
Silt (%)	17.0
Clay (%)	12.0
Textural class	Sandy loam
Bulk density (g cm^{-3})	1.41
Volumetric soil moisture content at field capacity (%)	10.10
Volumetric soil moisture content at permanent wilting point (%)	4.80
pH 1:2.5 (H_2O)	8.00
EC (dS m^{-1}) in 1:2.5 soil to water ratio	0.10
$CaCO_3$ (%)	6.00
Soil organic matter (%)	1.31
Total N (%)	0.10
Available P (mg kg^{-1})	4.56
Exchangeable Ca (cmol(+) kg^{-1})	6.20
Exchangeable Mg (cmol(+) kg^{-1})	0.90
Exchangeable Na (cmol(+) kg^{-1})	0.28
Exchangeable K (cmol(+) kg^{-1})	0.86
Cation exchange capacity (cmol(+) kg^{-1})	9.00
Base saturation (%)	91.55

Table 2. Effects of P on height, ear length, shoot dry matter and total above ground biomass weight of maize grown on Fluvisols

Applied P (kg P ha^{-1})*	Plant height (cm)	Ear length (cm)	Shoot dry matter (kg ha^{-1})	Total above ground biomass (kg ha^{-1})
0	129.8c	12.45c	3779.2	5741b
10	154.2abc	13.43bc	4008.7	6466ab
20	157.2abc	13.58abc	4349.2	7117a
30	162.6ab	15.32ab	3837.9	6873ab
40	180.7a	15.61a	4058.9	7142a
50	142.3bc	14.16abc	3844.6	6040ab
60	148.3bc	13.88abc	3797.5	5847b
LSD (0.05)	26.59	1.997	NS	1191.0
CV (%)	8.66	7.11	18.54	9.22

*Means within a column followed by the same letter are not significantly different at $P > 0.05$. NS = Non-significant; LSD = Least significant difference; CV = Coefficient of variation

Above ground biological and shoot dry matter weight

Above ground biomass weight (grain plus shoot) production by maize significantly ($p \leq 0.05$) increased over the control treatment at the applied P rates of 20 and 40 kg P ha^{-1} (Table 2). Highest total dry matter weight was observed at 20 kg P ha^{-1} treatment. These results are in agreement with the findings of Sarhadi-Sardoui *et al.* (2003) who showed that in soils with lower available P corn dry matter increased significantly but high rates of P, either did not increase or at certain P levels decreased it (Table 2). Shoot dry matter weight showed no significant difference due to P application. Even though the differences were statistically insignificant most of the results in the fertilized plots were higher in figure than the control plot with highest figure at 20 kg P ha^{-1} (Table 2).

Grain yield and yield components

Phosphorus application significantly ($P \leq 0.01$) increased maize grain yield at the site (Table 3). The check and 30 kg P ha^{-1} treatments resulted in lowest and highest grain yields respectively (Table 3). Significant increase in maize grain yield due to P application at the site is indicative of low inherent soil P. Wasonga *et al.* (2008) had similarly reported significant increment in maize grain yield due to application of P in Kenya. This is also in line with findings of Kogbe and Adediran (2003) who obtained results showing that maize grain yield responded positively well to P application but at higher rates, the yield was depressed in Nigeria. The results indicated maximum grain yield at 30 kg P ha^{-1} and decreased after this P level (Table 3). The economic optimum yield obtained by calculating the marginal return was at 30 kg P ha^{-1} (Table 4).

Table 3. Effects of P on grain yield and some yield components of maize grown on Fluvisols

Applied P (kg P ha^{-1})*	Grain yield (kg ha^{-1})	1000 grains weight (g)	Number of grains ear^{-1}	Grain harvest index
0	1961b	264.0c	215.8	0.343
10	2476ab	304.8ab	273.4	0.383
20	2768ab	284.2abc	247.9	0.393
30	3035a	317.0a	280.5	0.443
40	2750ab	288.5abc	270.1	0.407
50	2196ab	288.5abc	191.5	0.373
60	2049ab	275.8bc	235.1	0.350
LSD (0.01)	928.8	36.60	NS	NS
CV (%)	12.46	4.18	18.87	15.47

*Means within a column followed by the same letter are not significantly different at P > 0.01. NS = Non-significant; LSD = Least significant difference; CV = Coefficient of variation

Table 4. Economic analysis of incremental grain response of maize to increasing rates of applied P on Fluvisols

Applied P (kg P ha^{-1})	Grain yield (kg ha^{-1})	Increment in P (kg ha^{-1})	Cost ($ ha^{-1})	Increment in yield (kg ha^{-1})	Value ($ ha^{-1})	Net return ($ ha^{-1})
0	1961	0	-	-	-	-
10	2476	10	55.32	515	139.95	+84.63
20	2768	20	110.64	807	219.29	+106.65
30	3035	30	165.96	1074	291.85	+125.87
40	2750	40	221.28	789	214.40	-6.88
50	2196	50	276.60	235	63.86	-212.74
60	2049	60	331.92	88	23.91	-308.00

Data presented in Table 3 showed that the effect of different rates of P fertilizer on number of grains per ear was not significant. Grain number increased from 215.8 in the control to 280.5 in 30 kg P ha^{-1} respectively then decreased (Table 3) but the difference was not statistically significant.

The treatments 10 to 50 kg P ha^{-1} gave significantly ($P \le 0.05$) higher different 1000 grain weights from over the control and the highest P treatments (Table 3). Phosphorus rate at 30 kg P ha^{-1} produced the maximum 1000 grain weight over others, with the minimum 1000 grain weight obtained in the control plot. Average weight of 1000 grains varied from 264 g in the control to 317 g in 30 kg P ha^{-1} during the growth period (Table 3).

Fertilizers P application did not significantly increase grain harvest index (HI). The implication here is that applied P rates did not improve dry matter partitioning to grains under the experimental condition. At 30 kg P ha^{-1}, the rate at which most of yield and yield component variables showed better response, the mean HI values was 0.44 (Table 3). The P harvest index obtained is similar to that reported by Fageria (2009) for corn which was typically 0.43 (Table 3).

Nitrogen and P uptake

Nitrogen uptake by maize grain is presented in Table 5. Fertilizer P applications at the rates from 20 to 40 kg P ha^{-1} significantly ($P \le 0.01$) increased the uptakes of grain N over the control treatment. Applied P rate of 30 kg P ha^{-1} was highest in grain N uptake which increased by 23.48 kg ha^{-1} above the control plot. Lower grain N uptakes were observed at the control and 50 and 60 kg P ha^{-1} treatments (Table 5). This result agrees with the results reported by Iowa State University of Science and Technology (1992) which had reported removal of a large portion of the N and P taken up by the plant in the maize grain that is harvested.

Table 5. Effect of P on grain, dry matter and total above ground N and P uptakes, soil P at harvest and P harvest index of maize grown on Fluvisols.

Applied P rate (kg P ha^{-1})*	Grain N uptake (kg ha^{-1})	Shoot N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})	Grain P uptake (kg ha^{-1})	Shoot P uptake (kg ha^{-1})	Total P uptake (kg ha^{-1})	Soil P (mg kg^{-1}) at harvest	P harvest index
0	27.85c	30.06	57.58c	1.31c	3.36b	4.67d	3.99d	0.280c
10	39.51abc	32.91	72.42abc	3.04c	4.66ab	7.70c	4.75d	0.39bc
20	45.20ab	35.03	80.23ab	6.60b	5.48a	12.08b	6.28cd	0.55ab
30	51.33a	32.25	83.58a	15.37a	5.87a	21.33a	8.59c	0.72a
40	45.98ab	37.59	83.07a	14.11a	5.70a	19.81a	13.84b	0.71a
50	35.30bc	33.06	68.36abc	7.55b	4.58ab	12.13b	17.12b	0.62a
60	31.51bc	32.41	63.92bc	7.05b	4.60ab	11.66b	22.97a	0.60a
LSD (0.05)	9.298	NS	16.940	1.844	1.512	2.590	3.471	0.166
CV (%)	12.03	17.16	7.70	7.75	7.75	6.70	10.35	10.08

*Means within a column followed by the same letter are not significantly different at P > 0.05 for shoot P uptake and at P > 0.01 for the other parameters. NS = Non-significant; LSD = Least significant difference; CV = Coefficient of variation

Table 6. Phosphorus apparent recovery (%) and use efficiencies (kg kg^{-1}) in maize under different rates of applied P.

Applied P (kg ha^{-1})	Apparent recovery (%)	Agronomic efficiency	Physiological efficiency	Agro-physiological efficiency	Utilization efficiency
10	25.78	43.75	245.51	145.68	63.29
20	31.54	34.31	185.70	132.65	58.56
30	47.26	28.70	67.99	64.46	32.13
40	32.22	16.78	70.55	52.08	22.71
50	12.69	3.99	40.18	31.41	5.10
60	9.91	1.25	15.23	12.61	1.51
Mean	26.57	21.46	104.19	73.15	30.55

Table 7. Regression analysis values relating applied P fertilizer and its use efficiencies on Fluvisols.

Type of P use efficiency	Regression equation	R^2
Agronomical efficiency	Y = 53.00 – 0.901X	0.98***
Physiological efficiency	Y = 180.00 – 4.312X	0.87***
Agro-physiological efficiency	Y = 171.30 – 2.804X	0.93***
Recovery efficiency	Y = 41.66 – 0.431X	0.34NS
Utilization efficiency	Y = 78.42 – 1.368X	0.96***

*** = Significant at P ≤ 0.01; NS = Non-significant; X = Applied P kg kg^{-1}; Y = P use efficiency

No significant difference was observed due to application of P in shoot dry matter N uptake (Table 5). This may be due to the translocation of P from lower parts to the grain. This result is also in agreement to that of Fageria (2009) who concluded that P requirements are higher for grain compared to shoot in the cereals as well as in the legumes.

Total N uptake significantly (P ≤ 0.01) increased at P application rates from 20 to 40 kg P ha^{-1}. Applied P rate of 30 kg P ha^{-1} was highest in N uptake which was observed to increase by 26 kg ha^{-1} (31.6 %) over the control plot. Lower total N uptakes were observed at both control and higher treatments (Table 5). This is supported by Tehseen (2005) who reported the influence of general nutrient status of the soil, including P on maize N uptake and indicated the increment in N uptake of maize in P applied case than in P deficient condition in Newzealand.

Grain P uptake of maize was significantly ($P \leq 0.01$) different from 30 and 40 kg P ha^{-1} than in the other P treatments. The highest P uptake was observed at 30 kg P ha^{-1} which was 15.37 kg ha^{-1} compared with the least at the control treatment (1.31 kg ha^{-1}). Tahseen (2005) similarly reported that during grain formation P moves from vegetative parts to grain, increasing the amount of P in the grain. The result shows higher grain P uptake than shoot P uptake (Table 5). This result agrees with the findings of Hussaini et al. (2008) in Nigeria who concluded that nutrient accumulation in the maize grain was greater than that in the other components of the plant. According to them, this can be attributed to the mobilization of large proportions of P from other parts of the plant to the grain as the grain developed. Shoot dry matter weight showed significantly ($P \leq 0.05$) higher P uptakes at 20- 40 kg P ha^{-1} then declined (Table 5) than the control treatment. Kizilgoz and Sakin (2010) similarly observed that high soil P supply significantly increased shoot P concentration in maize.

Above ground P uptake of maize was significantly ($P \leq 0.01$) higher at 20 to 60 kg P ha^{-1} than in the other P treatments. The highest P uptake was observed at 30 kg P ha^{-1} which was 21.33 kg ha^{-1} compared with the least at the control treatment (4.6 kg ha^{-1}), (Table 5). The result agrees with that of Tahseen (2005) who concluded that fertilizer P application increased total P uptakes of maize and corn. Sarhadi-Sardoui *et al.* (2003) too showed that application of P increased corn P uptake.

Phosphorus harvest index which is P harvest in grain over P harvest in grain plus shoot increased from 0 to 30 kg P ha^{-1} then declined showing significant ($P \leq 0.01$) difference between P rates of 10 to 60 kg P ha^{-1} and the control plot (Table 5). The P harvest index obtained is lower than that reported by Fageria (2009) for corn which was 0.79. This variation may be attributed to differences in crop variety as well as other environmental factors.

The fertilizer P addition from 10 to 60 kg P ha^{-1} increased the Olsen P test values from 4.8 to 23 mg P kg^{-1} soil at the time of harvest (Table 5). Tehseen (2005) obtained that fertilizer P addition of 15 and 70 Kg P ha^{-1} increased the Olsen P test values from 11 to a maximum of 16 mgPkg^{-1} soil.

Phosphorus use efficiency of maize

Phosphorus use efficiency (PUE) of maize is shown in Table 6. The higher the rates of P application, the lower were the different types of P use efficiencies. This indicates that the efficiency of maize in P utilization decreased as the P fertilizer rate increased. On the average, every kilogram of P applied to maize produced 30.55 kg of grain when P utilization efficiency was considered. The highest P utilization efficiency was observed at 10 kg P ha^{-1} at the site (Table 6). This agrees with findings of Kogbe and Adediran (2003) who concluded that P use efficiency of maize varieties was higher at lower rate of P application but lower at the higher PUE. They inferred that the efficiency of maize in P utilization decreased as the P fertilizer rate increased. When the rate at which most of measured parameters showed the highest response to P application which is at 30 kg P ha^{-1}, P utilization efficiency was 32.13 kg kg^{-1} (Table 6). This finding is in confirmation with Fixen (2004) who reported that the first crop following P application usually takes up only 5-30% of the P applied. He concluded that fist year recovery of P is low, not because the P is immediately “fixed” into plant unavailable forms but because it moves so little in soils that crop roots are too far from much of the fertilizer-soil reaction zones to be accessed. However, Van der Eijk (1997) stated that phosphorus deficiency in many Kenyan soils is largely due to P-fixation. Chaudhary *et al.* (2003) also reported high increase in P sorption at higher fertilizer rates than at lower rates The results are also in agreement to that of given in FAO (2008). Wasonga *et al.* (2008)

too had reported higher P physiological efficiency in the plots that received fertilizer P in a P deficient sandy loam soil in Kenya. They concluded that P application is likely to improve root system and enhance uptake of P, in addition to other essential plant nutrient elements as well as moisture.

Table 7 indicates different types of P use efficiencies of maize on Fluvisols in the study area. The R^2 values of regressing P rate with the different P use efficiencies showed highly significant ($P \leq 0.01$) difference except for P recovery efficiency which was non significant. The P utilization efficiency of 32.13 kg P ha^{-1} shows that one kilogram of P increases 32.13 kilogram of maize grain yield in one hectare when .30 kg P ha^{-1} was applied. The apparent recovery efficiency of 47.26 % also indicates the percentage of the applied P use by maize in one cropping season.

Conclusion

The results of the study indicated that application of P to maize on Fluvisols in Ethiopia were significant in yield and some yield components as much as the soils of the area are inherently low in P. It was observed that additional P input to soil P is highly important in the area in order to obtain desirable effect on maize performance. The results indicate that increasing in P rate beyond 50 kg ha^{-1} would depress yield, growth, N and P uptakes and P use inefficiencies of the maize crop. Yield depressions observed at the high P rates (50 and 60 kg P ha^{-1}) were expressed in the various crop parameters measured. Reliance on blanket fertilizer recommendation may not be able to provide adequate measure for efficient use of fertilizer in maize production. This also indicates that the blanket recommendations being applied in many places in Tigray as well as in Ethiopia are not always optimum which calls for detail crop, soil management and environmentally specific research as well as soil nutrient determination before use of P fertilizer. The agronomic efficiency of maize was highest at the rate of 10 kg P ha^{-1} whereas at the economically optimum rate (30 kg P ha^{-1}), the agronomic efficiency was lower (28.7 kg grain kg^{-1} P). Therefore, applying the concept of agronomic efficiency and other types of efficiencies to P has to be seen with other factors such as the optimum yield, the amount of P accumulated in the soil, as well as its effect on other plant nutrients. This is because highest P efficiencies occur when inadequate amounts are applied at low soil test levels. It can be concluded that 30 kg P ha^{-1} gave economically optimum yield of maize. The results further indicated that there may be a potential for improvement of P use efficiency especially when other deficient plant nutrients like N are corrected

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