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Response and economic feasibility of maize (*Zea mays* L.) to P fertilization in acidic Alfisols of North-western Ethiopia

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Abstract

Background: Phosphorus is believed to be the second most limiting nutrient for crop growth and development in acidic soils. It is mainly because the amount of P in the soil is inherently low and part of it is fixed and made unavailable to plant uptake. Therefore, the objective of this research was to study the response of maize to mineral P fertilizer application and evaluate its economic feasibility on acidic Alfisols of North-western Ethiopia.

Results: Results of the experiment indicated that phosphorus fertilizer rate had a significant ($p < 0.05$) effect on plant height, shelling percentage, number of kernel per ear, number of ears per plant, grain yield, dry stubble yield and dry biomass yield. However, it did not have a significant effect on lodging percentage and 1000-grains weight. Increasing the P rate only up to 30 kg P_2O_5 ha⁻¹ gave a significant grain yield increase over the control. Similarly, the marginal rate of return (MRR) analysis showed that the same rate gave MRR of 67.8 % while others were dominated by the same.

Conclusions: From the results of the experiment it was possible to conclude that, in the presence of sufficient amount of N and K fertilizers, maize is responsive only to lower levels of phosphorus fertilizer application. Apparently, the fertilizer application at the rate of 30 kg P_2O_5 ha⁻¹ gave maximum profit from unit investment. Going beyond this P level did not bring profitable yield increase.

Keywords: Alfisols, Marginal rate of return, Optimum grain yield, P fertilizer rate

Background

There is a wide range of controversy in worldwide reports regarding the most limiting nutrient for plant growth and development. Mesfin (1998) and Yihenew (2007) reported that nitrogen to be more often deficient than any other essential element on Alfisols of Ethiopia. Linquist and Sengua (2003) also showed that N to be the most limiting nutrient in rain fed lowland rice soils of Laos in Southeast Asia. Some reports, however, indicated that phosphorus to be the major yield-limiting nutrient in the highly weathered acidic soils of the tropics (Sanchez and Salinas 1981; Sahrawat et al. 1995, 1997). Enwezer (1977) also reported that phosphorus to be the most limiting nutrient in acidic soils of Southeastern Nigeria. Similarly,

Verma and Tripathi (1982) showed that wheat grown on Alfisols of the Himalayan regions of India suffered from an extreme phosphorus deficiency. In the study area, little information is available on the response of maize to phosphorus application and its economic return in acidic Alfisols of Northwestern Ethiopia.

Phosphorus has more wide spread influence on both natural and agricultural ecosystems. In agricultural ecosystems, phosphorus constraints are much more critical because phosphorus is removed from the system in the harvested crops with only limited quantities being returned in crop residues and animal manures (Brady and Weil 2002). Phosphorus does not occur as abundantly in soils as N and K. Total P in surface soils varies between 0.005 and 0.15 % and unfortunately the quantity of total P in soils has little or no relationship to the availability of P to plants (Havlin et al. 1999). Because part of the total

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P can be in fixed form in acidic soils and is not readily available to plant uptake. Therefore, following nitrogen, phosphorus is the most limiting nutrient in the tropics (Sanchez 1976) and in Ethiopia (Yihenew 2007).

Phosphorus is also of primary concern in the appraisal of the soil resources of Ethiopia (Miressa and Robarge 1996) since most of the soils on the highland plateau are reported to be deficient in phosphorus (Asnakew et al. 1991; Desta 1982; Tekalign et al. 1988; Yihenew 2002). Phosphorus is one of the most limiting elements in the majority of the Alfisols of Ethiopia (Mesfin 1998). In P-deficient soils, crops usually recover less than 10 % of the applied amount of phosphorus in the first season and the total recovery after four years is often only 20–30 % (Russel 1972). In addition to the inherently low available P content, the high P fixation capacity of these soils made the problem complex. Tekalign and Haque (1987) and Taye (1998) have reported a sorption range of 150–1500 $\mu\text{g g}^{-1}$ in several Alfisols of Ethiopian highlands.

Inherent P deficiency and high P fixation capacity of these soils eventually led to severe yield decline in Northwestern Ethiopia. This calls for using more inputs to meet the P nutrient demand of crops. Yihenew (2003) also reported that the soil P critical level measured by

Bray II method (Sahlemedihin and Taye 2000) for maize is 14.6 mg kg^{-1} in Alfisols of Northwestern Ethiopia. However, there is a complaint from the extension system that some soils having P content below the critical level are not responding while some having P contents above the critical level are responding to P fertilization. Hence, before going to large scale P application, it is critical to know the response levels and its economic return. The objective of this research was, therefore, to study the response of maize to mineral P fertilizer application over several locations and evaluate its economic feasibility on Alfisols of Northwestern Ethiopia.

Methods

Site selection

To select the experimental sites, composite soil samples were collected from 52 farmlands that had different cropping history, slope and management practices. The collected soil samples were analyzed for available P (Olsen and Sommers 1982), texture (Bouyoucos 1962) and pH (Thomas 1966). Out of the sampled sites, 20 experimental sites covering the widest possible ranges of the indicated parameters were selected (Table 1). This was done to accommodate all ranges of soils with varied major physico-chemical properties in the study area.

Table 1 Locations and some chemical and physical characteristics of soils of the experimental sites

| Site No. | Altitude (meters above sea level) | Geographic position | Slope (%) | Bray-2 P (mg kg^{-1}) | pH in H_2O (1:2.5) | Particle size (%) | | | Textural class |
|----------|-----------------------------------|---------------------|-----------|----------------------------------|------------------------------------|-------------------|------|------|-----------------|
| | | | | | | Sand | Silt | Clay | |
| 1 | 2240.0 | 11°17.2'N 37°28.9'E | 3.8 | 3.42 | 4.91 | 7 | 25 | 68 | Clay |
| 2 | 2243.1 | 11°17.3'N 37°28.8'E | 2.6 | 2.55 | 5.21 | 5 | 25 | 70 | Clay |
| 3 | 2348.8 | 11°14.3'N 37°30.7'E | 0.3 | 3.82 | 5.00 | 7 | 21 | 72 | Clay |
| 4 | 2347.9 | 11°14.2'N 37°30.9'E | 2.3 | 2.81 | 5.35 | 13 | 17 | 70 | Clay |
| 5 | 1897.3 | 11°44.0'N 37°30.8'E | 5.4 | 10.80 | 5.40 | 15 | 29 | 56 | Clay |
| 6 | 1918.0 | 11°44.7'N 37°31.9'E | 5.1 | 3.13 | 4.73 | 5 | 17 | 78 | Clay |
| 7 | 1955.8 | 11°45.7'N 37°32.4'E | 3.1 | 8.02 | 4.99 | 7 | 27 | 66 | Clay |
| 8 | 1969.8 | 11°46.8'N 37°33.2'E | 2.3 | 10.73 | 4.83 | 9 | 27 | 64 | Clay |
| 9 | 1916.8 | 11°44.4'N 37°31.7'E | 8.1 | 11.41 | 5.26 | 55 | 21 | 24 | Sandy clay loam |
| 10 | 2048.7 | 11°24.8'N 37°24.8'E | 1.1 | 9.43 | 5.25 | 9 | 25 | 66 | Clay |
| 11 | 2067.6 | 11°25.0'N 37°07.9'E | 3.5 | 7.59 | 5.25 | 15 | 49 | 36 | Silty clay loam |
| 12 | 2039.8 | 11°24.8'N 37°07.4'E | 0.2 | 6.66 | 5.05 | 9 | 25 | 66 | Clay |
| 13 | 2038.9 | 11°24.6'N 37°07.1'E | 0.3 | 6.48 | 5.13 | 11 | 23 | 66 | Clay |
| 14 | 2002.7 | 11°21.6'N 36°58.1'E | 1.6 | 10.96 | 5.01 | 13 | 23 | 64 | Clay |
| 15 | 1900.0 | 10°80.0'N 36°85.0'E | 5.0 | 7.96 | 5.75 | 11 | 21 | 68 | Clay |
| 16 | 2150.7 | 10°42.7'N 37°05.6'E | 1.8 | 16.04 | 5.78 | 15 | 25 | 60 | Clay |
| 17 | 2106.3 | 10°42.2'N 37°06.3'E | 5.2 | 9.48 | 5.43 | 9 | 21 | 70 | Clay |
| 18 | 1897.9 | 10°40.8'N 37°16.4'E | 2.3 | 9.48 | 5.63 | 11 | 23 | 66 | Clay |
| 19 | 1888.4 | 10°40.5'N 37°16.4'E | 2.9 | 4.14 | 5.42 | 11 | 23 | 66 | Clay |
| 20 | 1882.0 | 10°40.9'N 37°19.0'E | 0.6 | 2.54 | 5.28 | 11 | 23 | 66 | Clay |

Experimental design, field layout and cultural practices

At each site, the field experiment was arranged in randomized complete block design with five P fertilizer rates (0, 30, 60, 90 and 150 kg P₂O₅ ha⁻¹) as triple superphosphate (0-46-0) and four replications. Plant spacing was 70 cm between rows and 30 cm between hills of each plant. The gross plot had three harvestable and two boarder rows (with 4.8 m length). Two plants in each end of the harvestable rows were used as boarder plants. Seed beds for maize planting in each location were prepared following farmers' practice. Planting was conducted depending on the onset of rainfall in different areas. Planting was made by keeping two seeds in one hill at a distance of 30 cm within a row. Two weeks after emergence plants were thinned to one plant per hill.

To each treatment, nitrogen (150 or 75 kg ha⁻¹ for sites with organic matter content <5 % and ≥5 %, respectively) as urea (46-0-0) and potassium (60 kg K₂O ha⁻¹) as potassium chloride (0-0-60) were added as basal fertilizers to avoid limitations of these macronutrients. All of phosphorus and potassium as well as half of nitrogen fertilizer rates for each treatment were applied at planting by banding along one side of the row at a distance of about 10 cm below and 5 cm aside the seeds. The remaining half of the nitrogen fertilizer for each treatment was applied at 35 days after emergence by banding along the row at a distance of about 10 cm below and 5 cm aside the seeds. Two times ridging and, as necessary, weeding operations were performed to all sites.

Data collection

Data on agronomic parameters (plant height and lodging percentage), yield components (number of ears per plant, shelling percentage, 1000-grain weight and kernel number per ear), and yields (grain, dry stubble and dry biomass) were collected as outlined in Yihenew (2004, 2007, 2015). Plant height from the ground level up to the collar of the upper leaf with developed leaf sheath was measured at 35 and 60 days after emergence, and at harvest. Lodging percentage was measured at harvest by dividing the number of lodged plants by the number of harvested stands. Those plants that inclined to the ground at an angle of <45° were considered lodged.

The number of ears per plant was determined by dividing the number of harvested ears by the number of harvested stands. Shelling percentage was measured as the ratio of the weights of shelled grain and unshelled ear expressed in percentage. Thousand-grain weight was determined by weighing with analytical balance the weight of 1000 sampled grains from the bulk harvest and adjusting it to 12.5 % moisture level. To determine the kernel number per ear, first shelled grain of the harvested maize in each plot was weighed and divided by the

number of ears. This gave grain weight per ear. After this, the weight of 1000 grains was determined. At last, kernel number per ear was determined mathematically as follows: kernel per ear = grain weight per ear (g) × 1000 grains/weight of 1000 grains (g).

Grain and stubble yield data were collected from the three harvestable rows by excluding over-favored plants (plants that stand at a spacing exceeding the required distance due to missing plants in a row). The harvested biomass was weighed for fresh biomass weight after which the ears and the stubble were separated and weighed. The ears were shelled and grain yield was determined by adjusting to 12.5 % moisture content. Stubble of two stands from each plot was collected from each plot at harvest. The stubble samples were oven dried until constant weight was attained so that it was possible to calculate the dry stubble yield per plot. The dried biomass yield was determined as the sum of dry grain and dry stubble yields.

Partial budget and marginal rate of return analysis of non-dominated grain yield responses for different N fertilizer rates were done following the method used by Nasreen and Farid (2003). $MRR = (\text{marginal increase in gross margin} / \text{marginal increase in variable cost}) \times 100$.

Results and discussion

The effect of phosphorus fertilizer rates agronomic properties

Plant height

Phosphorus fertilizer rate had a significant effect ($p < 0.05$) on plant height measured at 35 and 60 days after emergence (Table 2). Onasanya et al. (2009) also reported a non-significant difference in plant height among phosphorus rates at earlier growth stage of maize (5 and 6 weeks after planting); but recorded a significant effect at later stages (7 and 8 weeks after planting). Maqsood et al. (2001), Ali et al. (2002), Sharar et al. (2003) and Ayub et al. (2002) reported a significant effect of P rates ($p < 0.05$) on plant height of maize. However, the variation among treatments had shown a decreasing tendency at harvest compared to the preceding measurements. This might be related to the possible fixation of released P through time by the acidic Alfisols, that could have high sorption sites, besides to the inherently low level of available P in the soil (Yihenew 2002, 2007). Comparing the regression curves of plant height measured at different growth stages of the plant, higher rates of P to attain maximum plant height was required at harvest (188.5 kg P₂O₅ ha⁻¹) followed by at 60 days after emergence (141.8 kg P₂O₅ ha⁻¹) and at 35 days after emergence (138.0 kg P₂O₅ ha⁻¹). This suggests that the crop's requirement for P fertilizer increases from the earlier stage to the later stage of plant growth with increase in biomass accumulation.

Table 2 The effect of phosphorus fertilizer rates on plant height, lodging percentage and shelling percentage

| Fertilizer rate (kg ha ⁻¹) | Plant height (cm) | | | Lodging percentage (%) | Shelling percentage (%) |
|---|-------------------------------|-------------------------------|------------|---------------------------|-------------------------------|
| | At 35 days after emergence | At 60 days after emergence | At harvest | | |
| 0 | 14.8 e | 101.8 e | 198.0 d | 15.23 | 78.31 b |
| 30 | 19.1 d | 122.6 d | 203.2 c | 13.79 | 79.54 a |
| 60 | 21.6 c | 133.6 c | 208.3 b | 12.79 | 79.89 a |
| 90 | 23.5 b | 139.0 b | 210.1 b | 11.55 | 79.95 a |
| 150 | 25.5 a | 147.7 a | 214.7 a | 10.42 | 79.96 a |
| F test | ** | ** | ** | ns | ** |

Means followed by a common letter in a column are not significantly different at $p < 0.05$

**, ns—F test significant and non significant at $p < 0.05$, respectively

Lodging percentage

P fertilizer rates did not have a significant effect ($p > 0.05$) on lodging percentage of maize plants (Table 2). The non-significant difference among treatments obtained in this experiment could be attributed to the basal N and K fertilizers applied to all plots that might have increased the overall resistance of plants to lodging; because, nitrogen improves root growth and anchorage capacity (Wilson 1930), while potassium strengthens the stems and increases resistance for breakage (Brady and Weil 2002). It is, however, worthy enough to note that even though not significant, plants in the treatment with no added fertilizer lodged more as compared to treatments with different rates of P fertilizer and it was apparent that lodging percentage decreased as P-rate was increased.

Shelling percentage

Shelling percentages of fertilized treatments had significant differences ($p < 0.05$) from the unfertilized treatment (Table 2). The variation, however, was non-significant ($p > 0.05$) among fertilized treatments. The effect of fertilizer rate on shelling percentage was similar to its effect on grain yield, number of kernel per ear and number of ears per plant. The shelling percentage values, almost in all cases, varied between 78 and 80 % regardless of the fertilizer rates or the type of fertilizer applied. Shelling percentage of 80 % has been used as a standard value to calculate maize yield in maize breeding programs of Amhara Regional Agricultural Research Institute, Ethiopia. This suggests that shelling percentage is a parameter that is more determined by the inherent genetic characteristics of the crop itself than by external influences. Jotshi et al. (1983) also did not find a significant difference in shelling percentage among 15 maize varieties grown in Kashmir. Nevertheless, Ali et al. (2002) reported that shelling percentage increased from 60.0 % in the control plots to 68.24 % in the treatment that received 120 kg ha⁻¹ phosphorus in Pakistan.

The effect of phosphorus fertilizer rates on yield components

The effect of P fertilizer rate on yield components (1000-grain weight, number of kernels per ear and number of ears per plant) is presented in Table 3. P fertilizer rate did not show a significant effect on 1000-grain weight; however, fertilized treatments had significant differences in number of kernels per ear and number of ears per plant ($p < 0.05$) from the unfertilized treatment but not among each other. Plots with higher levels of P fertilizer tended to increase the number of grains carried by each ear and to develop more ears than to increase the kernel weight. This phenomenon usually happens in years when the rainfall distribution during the growing season does not limit plant growth and development up to grain filling (Yihenew 2004). However, Ali et al. (2002) reported that P rates significantly ($p < 0.05$) affected 1000-grain weight, number of kernels per ear and number of ears per plant. Maqsood et al. (2001) also reported significant effect of phosphorus fertilizer rates on number of cobs per plant, number of grains per cob and 1000-grain weight. Similarly, Onasanya et al. (2009) and Sharar et al. (2003) indicated that phosphorus rates significantly

Table 3 The effect of phosphorus fertilizer rates on yield components

| Fertilizer rate (kg ha ⁻¹) | 1000-grain weight (kg) | Number of kernels per ear | Number of ears per plant |
|---|------------------------------|------------------------------|-----------------------------|
| 0 | 0.4186 | 355.23 b | 1.0068 b |
| 30 | 0.4213 | 377.33 a | 1.0307 a |
| 60 | 0.4182 | 390.23 a | 1.0293 a |
| 90 | 0.4172 | 396.67 a | 1.0397 a |
| 150 | 0.4120 | 399.66 a | 1.0435 a |
| F test | ns | ** | ** |

Means followed by a common letter in a column are not significantly different at the 5 % probability level by DMRT

**, ns—F test significant and non significant at $p < 0.05$, respectively

affect 1000-grain weight and the minimum weight was obtained from the control. However, Sharar et al. (2003) reported that P rates did not affect number of cobs per plant. Generally, the analysis of variance showed that the variation among treatments for the number of kernels per ear and the number of ears per plant data were similar to the variation obtained among treatments for grain yield.

The effect of phosphorus fertilizer rates on yield parameters

The treatment with fertilizer rate of 30 kg P₂O₅ ha⁻¹ had a significant ($p < 0.05$) grain yield difference from the unfertilized treatment (Table 4). Increasing P fertilizer rate from 30 kg P₂O₅ ha⁻¹ did not give statistically significant ($p > 0.05$) grain yield increase even though yield increase was observed up to P fertilizer rate of 90 kg P₂O₅ ha⁻¹. Application of 150 kg P₂O₅ ha⁻¹, however, reduced the absolute grain yield as compared to the preceding treatment. It is also worthy enough to note that the absolute grain yield difference among treatments was not high. It could be due to the N and K basal fertilizers applied to all plots which could be more limiting than K. Yihew (2007) also reported that N is more limiting than P in the same soils. In contrast to the results of this

experiment, Ali et al. (2002) reported a significant yield increase up to the application of 120 kg ha⁻¹ phosphorus. Similarly, Maqsood et al. (2001), Sharar et al. (2003); Onasanya et al. (2009) also reported significant ($p < 0.05$) effect of phosphorus on grain yield. Dry stubble and dry biomass yields were more affected by P fertilizer rates than grain yield. Application of 90 kg P₂O₅ ha⁻¹ gave significantly higher dry stubble and dry biomass yields ($p < 0.05$) compared to treatments with 0 and 30 kg P₂O₅ ha⁻¹. The highest P rate (150 kg P₂O₅ ha⁻¹), however, depressed dry stubble and dry biomass yields.

Economic evaluation

Gross return was calculated from price (seasonal average) of maize grain in the study area (0.6 Birr kg⁻¹; Note: 1\$ = 21 Birr by November 2015). Variable cost was calculated from the costs involved for purchase and application of fertilizer. DAP, which is the source of phosphorus, was bought for 2.3 Birr kg⁻¹. For application of fertilizer at planting, 80 Birr ha⁻¹ would be needed considering that 16 laborers can apply the fertilizer on a hectare of land in one day. The partial budget analysis of fertilizer rates revealed that the maximum gross margin was attained from application of 30 kg P₂O₅ ha⁻¹ and the least gross margin was obtained from the application of 150 kg P₂O₅ ha⁻¹ (Table 5). The dominance analysis showed that all the treatments, except the unfertilized treatment and the treatment with P fertilizer rate of 30 kg P₂O₅ ha⁻¹, were cost dominated; i.e., they provided gross margin that were less than that of the preceding treatment. Therefore, these treatments were omitted from the analysis of marginal rate of return (MRR).

The MRR analysis showed that the treatment with P fertilizer at the rate of 30 kg P₂O₅ ha⁻¹ gave MRR of 67.8 %. It is worthwhile to note that the basal N and K fertilizers applied to all plots in this experiment might have diminished the yield variations among treatments that eventually reduced the variations in gross income. This suggests that phosphorus application at the rate of 30 kg P₂O₅ ha⁻¹ could be enough for optimum yield and

Table 4 The effect of phosphorus fertilizer rates on grain, dry stubble and dry biomass yields

| Fertilizer rate (kg ha ⁻¹) | Grain yield (kg ha ⁻¹) | Dry stubble yield (kg ha ⁻¹) | Dry biomass yield (kg ha ⁻¹) |
|--|------------------------------------|--|--|
| 0 | 4275.42 b | 6717.75 c | 10458.74 c |
| 30 | 4918.37 a | 7681.96 b | 11985.53 b |
| 60 | 5167.86 a | 8167.68 ab | 12689.66 ab |
| 90 | 5346.73 a | 8468.45 a | 13140.79 a |
| 150 | 5240.23 a | 8086.18 ab | 12661.51 ab |
| F test | ** | ** | ** |

Note: Means followed by a common letter in a column are not significantly different at the 5 % probability level by DMRT

** , ns—F test significant and non significant at $p < 0.05$, respectively

Table 5 Partial budget and dominance analysis of maize grain yield response for different P fertilizer rates

| P fertilizer rate (kg ha ⁻¹) | TSP (kg ha ⁻¹) | Grain yield (kg ha ⁻¹) | Gross return (Birr ha ⁻¹) | Variable cost (Birr ha ⁻¹) | | | Gross margin (Birr ha ⁻¹) | Cost dominance ^a | MRR (%) |
|--|----------------------------|------------------------------------|---------------------------------------|--|------------------------|-------|---------------------------------------|-----------------------------|---------|
| | | | | Fertilizer | Fertilizer application | Total | | | |
| 0 | 0.0 | 4275.4 | 2565.3 | 0.0 | 0.0 | 0.0 | 2565.3 | – | |
| 30 | 65.2 | 4918.4 | 2951.0 | 145.0 | 80.0 | 230.0 | 2721.1 | ND | 67.8 |
| 60 | 130.4 | 5167.9 | 3100.7 | 299.9 | 80.0 | 379.9 | 2720.8 | D | – |
| 90 | 195.7 | 5346.8 | 3208.0 | 450.1 | 80.0 | 530.1 | 2677.9 | D | – |
| 150 | 326.1 | 5240.3 | 3144.1 | 750.0 | 80.0 | 830.0 | 2314.1 | D | – |

^a Non-dominated (ND) are treatments that gave higher gross margin than treatments with lower N fertilizer rates; dominated (D) are treatments that gave lower gross margin than treatments with lower N fertilizer rates

maximum profit in conditions of sufficient nitrogen and potassium fertilizers were applied.

Conclusions

From the results of the experiment it was possible to conclude that in the presence of sufficient amount of N and K fertilizers, maize is responsive only to lower levels of phosphorus fertilizer application. Apparently, the fertilizer application at the rate of 30 kg P₂O₅ ha⁻¹ gave maximum profit from unit investment. This result suggests that all acidic soils may not be deficient in phosphorus. Hence, understanding the limiting nutrients for each soil type is necessary.

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Competing interests

The author declares that he has no competing interests.

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