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Effects of Methods and Rates of Phosphorus Fertilizer Application and Planting Methods on Yield and Related Traits of Maize (*Zea mays* L.) on Soil of Hawassa Area

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Abstract

An experiment was conducted to determine optimum rate and efficient method of phosphate fertilizer application and planting arrangement in maize at Hawassa. The treatment included one and two seeds per hill planting, spot and strip method of P fertilizer application and P levels of 0, 23, 46, 69 and 92 kg P_2O_5/ha. The results showed that higher mean values were obtained with one seed per hill planting which gave 5.1% grain yield advantage over two seeds per hill planting. Strip method of application had highly significant effect on grain yield and had 25 % yield advantage over spot method. However, P fertilizer rates had no significant effect and were negatively correlated with grain yield (r^2 = -0.7). One seed plating per hill planting is recommended whereas applying P fertilizer beyond 20kg P_2O_5/ha is not advisable for production of maize at Hawassa and surrounding area.

Key words: maize, planting method, phosphorus application method

1. Introduction

Maize (Zea mays L.) is the most important of the cereal crops after wheat and rice, and is widely cultivated in the world. It is one of the highest yielding cereal crops (Ahn 1993). Maize was introduced to Ethiopia during the late 16th or early 17th century (Huffnagel 1961). Since its introduction, it has gained importance and became first in total production and yield among the cereals (Benti & Joel 1993). Its national average yield is about 1.9 ton/hectare with a growth rate of 3.3% between 1996 and 1997 (CSA 1997). Reports indicate that the yield potential of maize in Ethiopia is over 10 t/ha. Poor performance of maize could in part be attributed to poor agronomic practice of farmers.

Maize gives greater yield and requires much more nutrient than other cereal crops (Schrimpf 1965). Maize is a heavy feeder with high N requirement. Its demand for P is also high and it is sensitive to a low phosphate supply particularly at early stages of growth. Because of this, it is sometimes used as a test crop to assess P deficiencies (Ahn 1993). The rapid growth of maize in the early stages is associated with its need for a liberal dressing of readily available nutrients at the very beginning. The beneficial effects of fertilizers can often be increased by the use of appropriate placement, especially when the spacing between rows is wide.

Wide ranges of soil types are available in the Southern Nations, Nationalities and People's Region (SNNPR). However, detailed soil analysis was not done in many zones of the Region. According to Murphy (1968), about 70% of the soils in northern Sidamo are low in available P. The low availability of P are much more expected in the reddish brown lateric soils, where 62% of which are slightly or more acidic. A diagnostic survey of phosphorus deficiency conducted by Desta (1982) around Hawassa and Yirgalem areas also revealed P deficiency for most of soil samples. The texture of the soils of the survey area ranges from sandy loam to clay loam. The dominant soil type in Wolayita area is Nitosol with pH of <5.5 to 6.7 and a texture of clay loam.

Reports from the Hawassa College of Agriculture (1991/1992) indicated that highest maize yield was obtained from 28 kg N /ha and 115 kg P_2O_5/ha in Hawassa area. Different recommendation rates were also reported for other places. At Areka, good yield response was obtained from 46 kg N/ha, but there was no response for applied phosphate fertilizers (ARC 1988). Assefa (1987) also studied the P fixing capacity of the soil at Areka and concluded that the response of maize to low rates of P fertilizer application was non-significant. On-farm trials, in the Shebedino Woreda, about 25 km south of Hawassa, showed that better yield could be obtained from 60 kg N/ha and 46 kg P_2O_5/ha (ARC 1993).

Fertilizer recommendations of the Ministry of Agriculture (MOA) for specific areas are based either on the pooling of trial results nationwide or extrapolating results of specific research center. The MOA has recently developed a package of technologies for maize where fertilizer rates were recommended based on soil types mainly color, irrespective of inherent soil properties and agro-ecology. Accordingly, recommended P_2O_5 rates range from 50.6 kg/ha (for Combisols and brown soil) to 80.5 kg/ha for Nitosols.

The amount of P in the soil solution at any one time is very small and usually considerably about one parts per million (ppm) (Ahn 1993). Available literature indicate that P is deficient in soils of different areas in southern Ethiopia and it is most of the time unavailable by forming insoluble phosphate compounds of Al, Fe and Ca (Murphy 1968; Desta 1982; Raya 1988). Thus, phosphate fertilizers applied at lower rates did not show significant responses in various experiments in southern Ethiopia (Assefa 1987; ARC 1988). Inorganic P availability can be influenced by microbial activity, soil temperature and pH. In most soils, P availability is highest in pH ranges of 6.0-7.5. Reactions of P with Al and Fe that are most prevalent at lower pH and with of Ca and Mg are more likely to occur at higher pH values all result in lower soil P availability.

In well-drained soils, phosphate ions normally do not move very far from their place of origin. The practical consequence is that the phosphate ions have to be very near to the plant root if they are to be readily absorbed (Ahn 1993). Placing water soluble phosphate fertilizers in pockets or drills along side of the plants or seeds will ensure the least possible direct contact with the soil particles and thereby P fixation will be reduced (Jacob & Uexkull 1958). A number of literature indicated that pop-up and band applications of phosphate fertilizers are more efficient than broadcast. Thus, particularly in areas of low pH and low P, only about half as much of the phosphate needed for the plant as is necessary with broadcasting be applied as band application (Russell 1978).

In the Sidama zone, farmers usually sow maize in rows. They drop one or two seeds per hill with variable planting distance and apply P fertilizers either by drilling in the furrows or with the seed. When they apply with the seed, they use bottle `cork' to measure the fertilizer rate. They apply one bottle 'cork' of DAP (= 4-5 g) for two seeds in a hill which is equivalent to 100 to 125 kg/ha of DAP. The few fertilizer rate trials carried out in the SNNPR did not as such consider methods of application. Method of P application, on the other hand, is supposed to increase the efficiency of nutrient uptake, particularly P, which in the final analysis reduces the amount of fertilizer required to apply for obtaining a specific yield level over the less efficient method. The aim of this project was therefore to find ways of efficient utilization of phosphate fertilizer through determination of optimum rate and efficient method of its application and planting arrangement in maize production on soils of Hawassa area

2. Materials and methods

2.1. Description of the experimental site

The experiment was conducted at Hawassa Research Center (HRC) which is located at 38^0 31'E longitude, 7^0 4'N latitude and at an altitude of 1700 meter above sea level. The HRC is located at 275 km south of Addis Ababa in Sidama administrative zone. The total annual rainfall at the Research Center averaged over years was 1073mm. The total amount of rainfall received during the experiment period (April to October 2006) was 746mm whereas the long term (26 years) average for the same period was 838mm. Average minimum and maximum air temperature and relative humidity during the experiment period were 14.1 ^oC, 26.3 ^oC and 69.6%, respectively. Soil temperature at 5-20cm depth was 24.1 ^0C. The soil at the Research Center is slightly acidic in reaction and loam in texture (ARC, 1993). It has 0.21% total nitrogen, 15.65 ppm P, 14.52 ppm iron and 20.30 me of/100 gm of calcium.

2.2. Treatments, experimental design and procedures

The three factors in this experiment were planting method, method of P fertilizer application and P fertilizer rate each having different levels. The planting methods were planting one seed per hill (**P1**) and planting two seeds per hill (**P2**). The plant population in both planting methods was 50,000 plants per hectare (ha). To maintain this number of plant population, the row spacing was made constant at 80cm whereas the spacing between plants or hills was 25cm for P1 and 50cm for P2. The two methods of P fertilizer application were spot (**M1**) and strip (**M2**) applications. In the case of spot application, the required level of fertilizer was placed together with the seeds, whereas, in the case of M2, the P fertilizer was drilled in the furrows. The five levels of fertilizer rate were 0 (**F1**), 23 (**F2**), 46 (**F3**), 69 (**F4**) and 92 (**F5**) kg P_2O_5/ha. Accordingly, the P fertilizer was weighed and applied per row base in the case of M2 and per plant base in the case of M1 and the whole rate of P for each treatment was applied just before sowing. The P fertilizer source was triple super phosphate (TSP) which consists of 46% P_2O_5. Nitrogen at a rate of 46 kg N/ha was applied in furrows as urea (46% N) to all plots in split application of 25% at planting and 75% at knee height stage of the crop. The three factor experiment was then conducted in a 2 x 2 x 5 factorial arrangement using a randomized complete block design (RCBD) with four replications. Accordingly, the field experiment consisted of 20 treatment combinations. A widely cultivated maize variety (BH-140) was used as a test crop.

2.3. Data collection and analysis

Crop data collected included stand count after thinning and before harvest, days to anthesis, silking and maturity, disease score (rust & blight), lodging, plant height, number of barren plants per plot, total number of ears harvested, ear length and diameter, seeds per ear, grain yield, total above ground biomass yield, 1000 kernel weight and harvest index. Grain yield and thousand kernel weight were adjusted at 12.5% moisture level. Days to anthesis and silking were taken when 50% of plants in a plot showed anther and silk, respectively. Days to maturity was taken when 50% of plants in a plot showed dried leaves and black scar on the kernels. Disease score was taken between 0 - 5 scale which was finally converted to percentage - 0 (0%) meant no infection and 5 (>85%) meant very heavy infection. Plants either fallen or inclined were considered as root lodging and those plants with broken stalk were considered as stem lodging. Plant height was measured from the ground level to the base of the tassel for ten randomly selected plants per plot, whereas ear length and diameter and seeds per ear were taken from three randomly selected ears per plot. Biomass weight was taken after sun drying for a number of days and when no change was observed between consecutive measurements. Two hundred fifty kernels were counted, weighed and converted to get thousand kernel weights. Harvest index was calculated by dividing grain yield by the total biomass weight. The plot size was 4m by 4m ($16m^2$) consisting of five rows. To avoid border effects, the data of all the parameters considered were taken from the three central rows, thus, the net plot size was $9.6m^2$.

Twenty composite surface (0-30cm depth) soil samples (one from each treatment) were collected before planting and immediately after harvest using auger. Available phosphorus was analyzed using Bray and Kurtz I method (Bray and Kurtz, 1945) using 0.03 N NH_4F and 0.025M HCl extractants and pH was determined electrometrically (1:2.5 soil: H_2O).

Statistical analysis was carried out using RCBD, factorial arrangement, following the procedure described by Gomez & Gomez (1984). Wherever significant and/or applicable, mean separations were carried out using Duncan's New Multiple Range Test.

3. Result and discussion

3.1. Effects of planting methods

Planting methods had significant ($P \leq 0.01$) effect on stand count after thinning and before harvest and on number of ears (Table 1). Higher number of plants after thinning and before harvest and higher number of ears were obtained from one seed/hill planting. One of the reasons for stand reduction in the two seeds per hill planting could be competition for resources. Fusseder (1985) also reported that nearby roots of maize compete for nutrients up to 75% for K and 40% for P. Lower number of stands before harvest resulted in low number of ears and biomass weight in the case of two seeds per hill planting.

Significant ($P \leq 0.05$) variations due to planting methods were also observed on root lodging, number of barren plants/plot and biomass weight (Table 1). Higher percentage of root lodging, number of barren plants and biomass weight were obtained with one seed per hill planting although it appears difficult to explain why higher percentage of root lodging and number of barren plants were observed on plots with one seed per hill planting compared with two seeds per hill. Higher plant height and number of ears might have contributed to root lodging with one seed per hill planting.

Planting methods had no significant effect on the other maize agronomic characters (most data not shown) including grain yield. Plant height, number of kernels/ear and grain yield were, however, better for planting of one seed/hill, whereas, higher thousand kernels weight was recorded for two seeds/hill planting. The two seeds per hill planting reduced grain yield by 5.1% as compared to one seed per hill planting.

Asnake (1998) also found non-significant effect of planting method on grain yield, plant height, days to maturity and thousand kernels weight in maize. Grain yield reduction with two seeds per hill could partly also be due to competition effect between plants in the same hill. Similar experiment done on cotton by Hawkins and Peacock (1970), however, revealed that yield obtained from three, four and five seeds/hill was significantly higher than two seeds per hill.

In the current study higher mean values of most characters of maize were recorded on plots planted using one seed/hill method. Thus, the contradicting result reported by Hawkins and Peacock (1970) with cotton plant could be explained by the differences in the amount of fertilizer applied (or nutrient status of the soil) and the plant species.

3.2. Effects of P application methods

Phosphorus fertilizer application methods had significant ($P \leq 0.01$) effect on stand count after thinning and before harvest, number of ears/plot, plant height, biomass weight/plot and grain yield (Tables 2). Higher number of plants after thinning and before harvest was recorded on plots with strip method of P fertilizer application. Similarly, strip application methods gave higher values of plant height, biomass weight, number of ears/plot and grain yield as compared to spot application. The grain yield obtained from strip method of application was 28% higher than that obtained from spot method of application. On soils with medium soluble phosphate, row placing and broadcasting phosphate are equally effective (Peterson, 1981) and this condition might favored strip application in this experiment. The other maize traits were not significantly influenced by application methods (most data not shown). However, higher mean values of barren plants and thousand kernels weight were recorded from spot application.

Pop-up (spot) fertilizer application in the seed zone of planting was shown by Clapp et al. (1970) to reduce plant stand in soy bean. Similarly the result of the current study showed lower number of plants with spot method of fertilizer application. Superior performance of strip application to spot application of P was also observed on plant height, biomass weight/plot, number of ears/plot and grain yield. Kresge (1967), however, observed grain yield increase in maize from application of solid fertilizer, containing N-P-K, in direct seed contact. Similarly, Okigbo (1973) reported that band application below the seed would increase maize stover yield and hasten tasseling and silking. Nevertheless, application method had no significant effect on tasseling and silking in this experiment. Okigbo (1973) on the other hand reported that band application below the seed would reduce plant height, number of ears and grain yield which are in agreement with the results observed from this experiment. Castilhos & Anghinoni (1983) also reported that P uptake and grain yield of maize were not affected by methods of P application.

According to Russell (1988), uptake of fertilizer P by young crop can be increased by placing water soluble P fertilizer close to the seed and this is very effective for soils low in phosphate. In the current investigation, however, placing P fertilizer near the seed (spot application) had no advantage for most of the agronomic characters of maize. This might be because of low uptake of the applied P as a result of adding P fertilizer to a soil of high P status (Russell 1988).

Relatively higher mean values of traits contributing to yield reduction such as root and stem lodging and barren plants were recorded on plots with spot method of fertilizer application. Besides these, low values of characters related to yield increment such as plant population, number of cobs, kernels/ear and biomass weight were also obtained from spot application signifying its adverse effect.

3.3. Effects of P fertilizer rates

Phosphorus fertilizer rates had no significant effect ($P \geq 0.05$) on grain yield (Table 3). Although non-significant, application of P fertilizer was negatively correlated with grain yield and, thus, a unit increase in P fertilizer rate decreased grain yield by 6.1 unit. The relationship between the applied P rates and grain yield showed decreasing trend of yield beyond application of 23 kg P_2O_5/ha (Fig 1). The control (no P fertilizer application) resulted higher yield as compared to application of 69 and 92 kg P_2O_5/ha. The yield obtained from no application was 10.6% greater than the highest P application rate, 92 kg P_2O_5/ha. Relatively better yield was obtained from 23 kg P_2O_5/ha which was 2.6 and 13.5 % higher than the yield obtained from no application and the highest application rate, respectively. Treatments with highest grain yield also gave the highest biomass weight per plot (Table 3 and Fig. 1), however, the variation was not statistically significant and P rates showed very low negative correlation with biomass weight.

Stand count after thinning and before harvest showed highly significant ($P \leq 0.01$) difference due to P application rates (Table 3). Stand counts in both cases were highest at lower P rates, i.e., 23 followed by 0 kg P_2O_5/ha. Like grain yield, number of plants/plot decreased linearly as P rates increased beyond 23 kg P_2O_5/ha in both cases (Fig. 2). When compared with no P fertilizer application, highest P rate (92 kg P_2O_5/ha) resulted in population reduction of 17.2% after thinning and 19.5 % before harvest. There was significant ($P \leq 0.01$) negative correlation (r^2=-0.90) between the applied P and the two stand counts.

Percentage of root lodging was highest on plots without P fertilization and variation between P fertilizer levels was highly significant (Table 3). Root lodging decreased linearly as P fertilizer rate increased. Lowest percentage was recorded on plots that received highest P level (92 kg P_2O_5/ha). Even though non-significant, stem lodging was also severe on plots that received lowest rates of P fertilizer (Table 3).

Number of ears harvested/plot was significantly ($P \leq 0.01$) affected by the P fertilizer levels (Table 3). Highest number of ears was harvested form 23 kg P_2O_5/ha followed by no P application. Number of ears decreased when P rate increased beyond 23 kg P_2O_5/ha. However, differences observed on the mean values recorded for plant height ear size, number of days to tasseling, silking and maturity, number of barren plants, kernels/ear and thousand seed weight were statistically significant (most data not shown).

According to Follett (1981), very low soil test value for P and very acid soil conditions improve the efficiency of band application. As soil test P increases, the yield response to P fertilization decreases (Halvin *et al*., 1999). The result of this experiment also showed that application of P fertilizer had no significant effect on grain yield and biomass weight, rather it has a tendency of reducing yield and thus lower rates of P gave better grain yield and biomass weight than higher rates (Table 3). This is related to the findings of Skarlou & Nuhas (1981) that plant dry matter and P content and fertilizer use efficiency decrease with increase in soil $CaCO_3$, while the level of applied P decrease in plant tissue with increase in soil P content. On the other hand, Kakhadz *et al.* (1986) reported that increasing P rates increased stover yield of maize.

Number of plants after thinning and before harvest was significantly influenced by P rates. Number of plants decreased linearly as P rates increased beyond 23 kg P_2O_5/ha in both cases (Table 3). Crop tolerance to osmotic pressure of the soil solution in the vicinity of the seed varies widely and maize is an intermediate in tolerance to osmotic pressure (Kresge 1967). The probability of P toxicity also increases at P contents higher than 1% in the dry matter. Hence, stand reduction in this experiment might have been caused by higher P fertilizer rates. Lower mean values observed on the other plant characters including plant height and number of ears/plot at higher P fertilizer rates would also be attributed partly to the same reason.

An increase in P fertilizer rate had more or less increased number of kernels/ear with the exception of the highest rate. Sander & Eghball (1988) also reported that as applied P increased, number of kernels/ear and number of ears of maize increased linearly.

Phosphorus enhances root development and strengthens straw of cereal crops and help to prevent lodging (FAO 1984). In the present investigation, percentage of root and stem lodging was lowest on plots that received higher rates of P (Table 3) which is in agreement with the observations made by FAO (1984). The role of P as plant nutrient is also manifested in its useful effect on flowering, seed formation and maturation and deficiency of P results a delay in maturity FAO (1984). However, number of days to tasseling, silking and maturity were not affected by the P rates in this experiment.

3.4. Interaction effects of planting and P application methods

Interaction between planting and P application methods had significant ($P<0.01$) effect on stand count after thinning while it had non-significant effect on stand count before harvest (Table 4). One seed/hill planting combined with strip method of P application had the highest stand both after thinning and before harvest followed by two seeds/hill combined with strip method of application. Comparing the interactions of the two factors against their independent effects, combining planting method with P application method brought no change on the results of the independent effects of planting and application methods on stand count.

Root and stem lodging, plant height and ear size were not significantly affected by the interaction of planting and P application methods (Table 4). However, both root and stem lodging were higher when one seed/hill was used with spot method of application. Whereas, plant height and ear size were highest with one seed/hill and strip method of P application.

The interaction had significant ($P\leq0.05$) effect on number of barren plants and biomass weight/plot (Table 4). Highest number of barren plants was observed on treatment combination of one seed/hill planting and spot application and the lowest number of barren plants was found in spot application and two seeds/hill planting. Highest biomass weight/plot was observed on plots with one and two seeds/hill planting combined with strip method of application and the lowest was from two seeds/hill combined with spot application.

Variations observed on number of ears/plot and kernels/ear and thousand kernel weight due to the interactions were not significant. Nevertheless, thousand kernel weight was highest with two seeds/hill planting and spot method of application at which level number of ears/plot and kernels/ear were lowest. Number of ears/plot was higher for one seeds/hill planting with strip method of application. Number of kernels/ear was highest (464gm) where thousand kernel weight was lowest (338gm), i.e., for one seed/hill planting combined with spot method of application.

The interaction had no significant ($P>0.05$) effect also on grain yield, numbers of days to tasseling, silking and maturity. The grain yield response varied from 3542 to 4771 kg/ha for the two seeds/hill with spot application and one seed/hill with strip application, respectively (Table 4). Similarly, Murphy (1958) observed better maize yield from broadcast planting with broadcast application of NP fertilizers followed by hill planting with hill application and drill planting with drill application, respectively on soils rich in available P. This shows that application methods have low importance on soils of good fertility status.

3.5. Interaction effects of planting methods and P rates

Interaction between planting methods and P rates had no significant effect (P>0.05) on all of the characters considered (Tables 5). However, grain yield was highest (4710.4 kg/ha) with one seed/hill and no P fertilizer application. Whereas the lowest (3635.4 kg/ha) was obtained with two seeds/hill and 69 kg P_2O_5/ha. Comparing the two planting methods at the same applied P rate, highest yield reduction of 23.2% and was observed with two seeds/hill planting at P rate of (69 kg P_2O_5/ha) followed by planting two seeds per hill with 92 kg P_2O_5/ha which resulted in yield reduction of 7.4%.

Though non-significant, highest mean values for most maize characters including stand count both after thinning and before harvest, root lodging, plant height, number of ears harvested and biomass weight were recorded from one seed/hill and 23 kg P/ha interaction (Tables 5). Stand count, particularly for two seeds/hill planting, linearly decreased as P fertilizer rates increased. Stand reduction was highest for the highest P rates when the same rate of P was compared at one and two seeds/hill planting. In general, root lodging and plant height decreased when planting method was changed from one to two seeds/hill for the same rates of P.

3.6. Interaction effects of application methods and P rates

The interaction of application methods and rates of P had significant ($P \leq 0.01$) effect on lodging, number of ears/plot, thousand kernel weight and grain yield (Tables 6). Sever root lodging was observed on plots that received 46 kg P_2O_5/ha using spot application. Number of ears/plot and grain yield were more favored by strip application at rates of 23 and 46 kg P_2O_5/ha, respectively. Number of ears/plot decreased as P rates increased particularly beyond 23 kg P_2O_5/ha for both methods of application. Grain yield also decreased as P rates increased above 23 kg P_2O_5/ha for spot application whereas it was variable for strip application. Highest thousand kernel weight (368 gm) was obtained from treatment combination of spot application and 69 kg P_2O_5/ha and the lowest (326 gm) was from strip application of 69 kg P_2O_5/ha. .

Independent or the main effects (Tables 2 and 3) of the two factors on root lodging were lower than their interaction effects. Thus, in the interaction, relatively higher rates of P applied in spot caused high percentage of root lodging. On the other hand, the interaction (Table 6) and the independent (Tables 2 and 3) effects of the two factors were similar on the number of ears/plot. However, thousand kernel weight was strongly affected by the interactions than the independent effects. Higher rate of P (46 kg P_2O_5/ha) but the same method of application (strip) like the main effects, gave the highest grain yield for the interactions.

Significant ($P \leq 0.05$) effect was also observed on stem lodging and biomass weight as a result of the interactions (Tables 6). Among the fertilized plots, number of plants lodged was higher on plots that received 23 kg P_2O_5/ha with spot application and 92 kg P_2O_5/ha with strip application. In general, at lower P rates, stem lodging was higher on spot applied plots, however, at higher rates, lodging was higher for strip applied ones. Stem lodging was not significantly affected ($P \geq 0.05$) by the main effects of each factor (Tables 2 and 3). For most of P rates, biomass weight increased on strip applied P than spot applied plots except for spot application of 23 kg P_2O_5/ha (Table 6). In general, the highest and the lowest biomass weight was recorded with strip application of 46 kg P_2O_5/ha and spot application of 69 kg P_2O_5/ha, respectively.

The variations observed on stand count, plant height, ear size, number of barren plants and kernels/ear due to the interactions were not statistically (most data not shown). Stand count both after thinning and before harvest increased with strip applied than spot applied plots and higher counts were recorded at lower rates of P fertilizer strip applied. However, stand count after thinning and before harvest were significantly ($P\leq0.01$) influenced by the independent effects of the two factors (Tables 2 and 3). Nevertheless, highest mean values of both stand counts were recorded from the lowest rates of P applied in strip both in the interactions and independent effects. Highest number of barren plants were recorded from 92 kg P_2O_5/ha applied in spot. The interaction had no significant effect on number of days to tasseling, silking and maturity.

3.7. Interaction effects of planting and P application methods and P rates

Most of the parameters considered were not significantly affected by the interactions among planting and P application methods and P fertilizer rates (Table 7). The only parameter that showed significant ($P\leq0.05$) difference was number of kernels/ear. Highest number of kernels/ear was recorded from the interaction of two seeds/hill of strip applied 46 kg P_2O_5 /ha.

Relatively, the grained yield obtained from the interaction of one seed/hill, strip application and 46 kg P_2O_5 /ha was better than others. The grain yield showed positive and significant ($P\leq0.05$) correlation (r^2=0.64) with total biomass weight and number of ears/plot. Stand count after thinning and before harvest were lowest on plots with two seeds/hill and 92 kg P_2O_5/ha applied in spot (Table 7).

The effect of interactions of the three factors on various maize characters was much different from the effects each factor showed independently. Most of the characters were significantly influenced by independent factors (Tables 1, 2 & 3) but not much affected by the interactions (Table 7). The only parameter that showed significant ($P\leq0.05$) difference due to the interactions, but not due to any of the independent effects, was kernels/ear. Despite the non significant difference, highest number of ears/plot was recorded for the same treatment in both the interaction and independent effects. The rate of P required to attain the highest grain yield was higher (46 kg P_2O_5 /ha) in the interaction than in the independent effect (23 kg P_2O_5/ha) although the methods of planting and P fertilizer application were the same in both cases. Stem lodging and thousand kernel weight were the only parameters which were not significantly affected both by the interactions as well as the independent effects of the three factors.

3.8. Soil phosphorus and reaction (pH)

Laboratory analysis of soil samples taken before applying fertilizer showed variation in pH among plots ranging from 6.2 to 7.1 (Table 8). However, analysis of soil samples taken after the execution of the experiment showed slightly reduced pH value & variation which ranged from 6.1 to 6.5. Simple linear correlation analysis revealed a non-significant ($P>0.05$) positive correlation (r^2= 0.71) between the pH values before and after the implementation of the experiment. The soil pH before planting was negatively correlated (r^2=-0.78) with soil P after harvest while it had a weak but positive correlation with grain yield.

Soil test P was also variable before and after conducting the experiment (Table 8). Soil test P before planting ranged from 31.2 to 70.3 ppm while the range after harvest was from 37.9 to 77.9 ppm. Averaged P levels over planting and application methods showed that more P after crop harvest was observed from plots treated with one seed per hill planting and strip method of application (Table 8). In general, applied P levels had positive and significant ($P\leq0.05$) correlation with soil P after harvest and therefore an increase in applied P was accompanied by an increase in soil P after harvest (Fig 3). There was a significant ($P\leq0.05$) negative correlation between grain yield and soil P after harvest. Thus, the higher the grain yield the lower was the soil P after harvest (Fig 4) which shows more P uptake from plots with higher grain yield. Similarly, there was very low negative association between initial soil P and grain yield as affected by P fertilizer application. Planting and P application methods had also some impact on soil P after harvest (Table 8). Soil P after harvest was lower on plots with one seed/hill planting and spot application as compared to two seeds/hill planting and strip application.

The initial pH range (6.2-7.1) and the pH range after the implementation of the experiment (6.1-6.5) were both within the optimum ranges. Mengel & Kirkby (1978) reported the optimum pH range for P availability in most mineral soils to be 6.0 to 7.0 whereas it was 6.0 to 7.5 according to Follett (1981). Thus, Fe and Al fixations of P are less likely expected.

The soil test value of P increased from 31.2-70.3 ppm before planting to 37.9-77.9 ppm after the harvest. The available P in both cases were higher than the amount required for P fertilizer recommendation (Desta 1978) and the P status of the soil was between medium to very high level (Bray & Kurtz 1945). Economic return for investment on annual P for maize was positive when soil test P values were less than 16 to 20 ppm (medium range) and negative when soil test P values were above this range (Webb *et al*. 1992).

3.8. Soil phosphorus and reaction (pH)

In conclusion, most characters of maize were affected by planting methods and higher mean values were obtained with one seed/hill planting which gave 5.3% advantage of grain yield over the two seeds/hill planting. Methods of P application had highly significant effect on various traits including grain yield. Strip method of application, which gave higher mean values for most traits, had 28% of grain yield advantage over the spot method of P application. Application of increasing levels of P fertilizer had no significant effect and was negatively correlated with grain yield. It was only the interaction between methods of application and rates of applied P that had significant effect on grain yield. The soil of the site had optimum pH and P test values. Thus, maize response for P application was very low and this implies P fertilizer application is not economical in this area. Yield decrease was observed with application of P fertilizer beyond 20kg $P_2O_{5/}$ha whereas the surrounding farmers apply 100kg $P_2O_{5/}$ha while they complain the high cost of fertilizer. Therefore, farmers of the area (Rift Valley zone of Hawassa area) should not apply P fertilizer more than 20kg $P_2O_{5/}$ha and they are advised to practice one seed plating per hill. Method of application may be more important in other areas where the soil is acidic and P level is most deficient.

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Table 1. Effect of planting methods on different agronomic parameters

Planting Methods	Number of plants/plot		Number of ears/ plot	Grain yield (kg/ha)	Biomass weight (kg/ha)	Lodging		Plant height (cm)	Number of barren plants/plot
	After thinning	Before harvest				Root (%)	Stem (No./plot)		
One seed/hill	40**	36**	35**	4323ns	14145*	33*	1.3ns	202ns	4.3*
Two seeds/hill	33	31	30	4104	13187	26	1.2	199	3.1
SE	0.8	0.8	0.8	0.10	333	2.1	0.19	1.6	0.3

* ,** significant at 0. 05 and 0.01 probabilities respectively, ns=non significant at 0.05, SE=standard error for mean

Table 2. Effect of P application methods on different agronomic and yield parameters of maize

Application methods	No. plants / plot		Number of ears/plot	Number of kernels/ear	Biomass weight (kg/ha)	Number of barren plants/plot	Plant height (cm)	Grain yield (kg/ha)	Harvest index
	After thinning	Before harvest							
Spot	32.77	30.13	28.33	451.5ns	12562	4.0ns	196.1	3719	0.298
Strip	40.57**	37.45**	36.78**	452.4	14770**	3.3	205.0**	4760**	0.323
SE	0.82	0.84	0.83	11.38	333	0.3	1.58	104	0.0062

** significant 0.01 probability, ns=non-significant at 0.05, SE=standard error for mean

Table 3. Effect of P fertilizer rates on different agronomic traits of maize

P_2O_5 rate kg/ha	No. plants / plot		Number of ears / plot	1000 kernel weight (gm)	Biomass weight (kg/ha)	Grain yield (kg/ha)	Lodging		Plant height (cm)	Number of barren plants/plot
	After thinning	Before harvest					Root (%)	Stem (No.)		
0	40a**	37a**	34.6ab	342ns	13416ns	4365ns	35a**	1.6ns	199.7ns	3.69ns
23	40a**	37a**	35.9a**	348	14583	4479	30ab	1.7	203.4	4.13
46	36ab	33ab	33.2abc	335	13802	4375	34a	0.8	202.4	2.94
69	34b	31b	29.1c	347	13083	3917	28ab	0.7	199.7	3.75
92	34b	31b	29.5bc	344	13447	3948	20b	1.4	198.4	3.94
SE	1.3	1.3	1.3	6.4	521	167	3.3	0.31	2.49	0.49

** significant at 0.01 probability, ns=non-significant at 0.05, SE=standard error for mean, means followed with the same letter along column are not significantly different from each other

Table 4. Effect of planting and P fertilizer application methods rates on different agronomic traits of maize

Treatments		No. of plants / plot		Number of barren plants/plot	Number of kernels /ear	Biomass weight (kg/ha)	Grain yield (kg/ha)	Lodging		1000 kernel weight (gm)
Planting method	Application method	After thinning	Before harvest					Root (%)	Stem (No./plot)	
1 seed/hill	spot	37b	34ns	5a*	464ns	13625a*	3885ns	34ns	1.3ns	338ns
1 seed/hill	strip	42a**	39	3b	450	14667a	4771	32	1.2	342
2 seeds/hill	spot	28c	26	3b	439	11510b	3542	25	1.2	351
2 seeds/hill	strip	40ab	36	3b	455	14875a	4667	26	1.3	341
SE		1.2	1.2	0.4	16.1	469	146	2.9	0.3	2.2

, * significant at 0.05 and 0.01 probability respectively; ns=non significant at 0.05 probability; SE=standard error for mean; means followed with the

same letter along column are not significantly different from each other.

Table 5. Effect of planting and P fertilizer rates methods rates on different agronomic traits of maize

Treatments		No. of plants /plot		Lodging		Plant height (cm)	Grain yield (kg/ha)	Biomass weight (kg/ha)	Harvest index
Planting methods	P_2O_5 rate (kg/ha)	After thinning	Before Harvest	Root (%)	Stem (No./plot)				
One seed /hill	0	41ns	39ns	35.63ns	1.25ns	203.35ns	0.36ns	13604ns	0.36ns
One seed /hill	23	43	39	37.88	2.13	205.50	0.31	14770	0.31
One seed /hill	46	38	34	36.25	0.75	202.19	0.31	14125	0.31
One seed /hill	69	38	34	27.25	0.75	200.31	0.30	14062	0.30
One seed /hill	92	39	36	28.00	1.63	200.69	0.29	14125	0.29
Two seeds /hill	0	38	35	34.38	2.13	196.13	0.32	13208	0.32
Two seeds /hill	23	37	35	22.00	1.25	201.31	0.32	14385	0.32
Two seeds /hill	46	33	32	31.25	0.88	202.63	0.33	13469	0.33
Two seeds /hill	69	31	28	29.50	0.75	199.19	0.30	12104	0.30
Two seeds /hill	92	28	26	12.75	1.25	196.06	0.30	12760	0.30
SE		1.85	1.89	4.64	0.44	3.50	0.014	740	0.014

ns=non-significant at 0.05 probability, SE=standard error for mean

Table 6. Interaction effect of P fertilizer rate and application methods on different agronomic traits of maize

Treatments		Stand count / plot		Lodging		Plant height (cm)	Number of ears / plot	1000 kernel weight (gm)	Grain yield (kg/ha)	Biomass weight (kg/ha)
Application method	P_2O_5 rates	After thinning	Before harvest	Root (%)	Stem (No./plot)					
Spot	0	38ns	35ns	33.7ab**	2.4a*	198ns	34ab**	334ab**	4354ab**	12948abcd*
Spot	23	38	35	22.2b	1.9ab	204	34ab	359ab	4396ab	14708a
Spot	46	31	28	43.9a	1.0abc	197	29bc	327b	3656bc	12308bcd
Spot	69	28	25	27.2ab	0.2c	191	21d	368a	3083c	11125d
Spot	92	29	27	21.9b	0.9bc	191	24cd	336ab	3073c	11719cd
Strip	0	41	38	36.2ab	0.9bc	202	35ab	349ab	4365ab	13864abc
Strip	23	42	39	37.6ab	1.5abc	203	38a	336ab	4575ab	14448ab
Strip	46	40	38	23.6b	0.6bc	208	37a	343ab	5104a	15292a
Strip	69	41	37	29.5ab	1.2abc	208	37ab	326b	4729a	15031a
Strip	92	39	34	18.9b	2.0ab	206	35ab	352ab	4823a	15167a
SE		1.8	1.9	4.64	0.44	3.5	1.8	9.04	229	739

*, ** significant at 0.05 and 0.01 probability respectively; ns-non-significant at 0.05 probability; means followed with the same letter along column are not significantly different from each other, SE=standard error for mean

Table 7. Interaction effects of planting and P application methods and P rates on different agronomic and yield parameters as affected

Treatment	Number of plants / plot		Lodging		Plant height (cm)	Number of barren plants /plot	Number of ears / plot	Number of kernels/ear	Biomass weight (kg/plot)	1000 kernel weight, gm	Grain yield (kg/ha)	Harvest index
	After thinning	Before harvest	Root (%)	Stem (No/plot)								
P1M1F1	41ns	39ns	31ns	1.2ns	201ns	3.7ns	36.2ns	490ab*	13802ns	330.5ns	4667ns	0.35ns
P1M1F2	43	37	25	2.5	2040	5.0	37.5	412ab	15750	355.2	4312	0.28
P1M1F3	34	30	52	1.0	198	4.0	29.2	484ab	12625	334.9	3469	0.28
P1M1F4	33	29	30	0.2	196	6.0	24.2	483ab	12364	358.0	3458	0.29
P1M1F5	36	34	33	1.7	193	6.7	29.0	451ab	13542	313.3	3521	0.26
P1M2F1	42	39	40	1.0	206	5.0	35.7	393b	13402	353.6	4344	0.33
P1M2F2	42	41	51	1.7	206	4.0	41.0	510ab	13802	337.4	4635	0.35
P1M2F3	43	39	21	0.5	207	2.0	38.5	429ab	15625	354.8	5281	0.34
P1M2F4	42	38	24	1.2	205	3.2	37.7	467ab	15750	324.6	4927	0.32
P1M2F5	42	37	23	1.5	208	3.0	37.0	451ab	14708	340.5	4646	0.32
P2M1F1	355	32	36	3.5	195	2.7	31.2	425ab	12104	337.8	4052	0.34
P2M1F2	33	32	19	1.2	203	3.0	29.7	475ab	13667	363.2	4490	0.33
P2M1F3	28	27	36	1.0	196	1.7	29.0	433ab	11979	319.7	3833	0.32
P2M1F4	23	20	24	0.2	187	3.5	18.5	453ab	9896	378.9	2740	0.27
P2M1F5	21	20	10	0.0	189	3.7	18.5	409ab	9896	358.5	2625	0.27
P2M2F1	41	37	32	0.7	197	3.2	35.2	440ab	14323	344.3	4385	0.31
P2M2F2	41	37	24	1.2	200	4.5	35.2	401ab	15104	335.3	4500	0.30
P2M2F3	38	37	26	0.7	209	4.0	36.0	518a	14969	331.3	4927	0.34
P2M2F4	39	36	34	1.2	211	2.2	35.7	459ab	14323	328.5	4521	0.32
P2M2F5	36	31	15	2.5	203	2.2	33.5	457ab	15625	363.5	4990	0.32
SE	2.6	2.7	6.6	0.6	4.98	0.98	2.62	36	1042	12.79	333	0.019

* significant at 0.05 probability, ns=non significant at 0.05 probability, means followed with the same letter along column are not significantly different from each other, SE=standard error for mean

Table 8. Soil test P and pH as affected by methods of planting and P application and P rates

Treatment	pH		Soil P (ppm)		Soil P after harvest averaged over planting & application methods (ppm)
	Before planting	After harvest	Before planting	After harvest	
P1M1F1	6.9	6.4	47.4	44.6	
P1M1F2	7.1	6.5	41.6	55.6	Planting methods
P1M1F3	6.9	6.3	44.6	47.4	1) one seed/hill…...58
P1M1F4	6.8	6.2	55.6	77.9	2) two seeds/hill…..68
P1M1F5	7.1	6.3	31.2	50.1	
P1M2F1	6.8	6.4	47.4	37.9	
P1M2F2	6.9	6.3	44.6	47.4	P application methods
P1M2F3	7.0	6.3	44.6	72.1	1) spot …….. 62
P1M2F4	7.0	6.3	55.6	77.9	2) strip……...64
P1M2F5	6.9	6.2	44.6	70.3	
P2M1F1	6.9	6.4	47.4	52.9	
P2M1F2	6.5	6.2	47.4	61.1	
P2M1F3	6.5	6.3	70.3	77.9	
P2M1F4	6.2	6.1	55.6	77.9	
P2M1F5	6.4	6.2	47.4	77.9	
P2M2F1	6.5	6.5	47.4	70.3	
P2M2F2	6.5	6.4	47.4	61.1	
P2M2F3	6.5	6.5	39.1	50.1	
P2M2F4	6.3	6.4	44.6	72.1	
P2M2F5	6.3	6.5	44.6	77.9	

Table 9. Soil test P and pH before planting and after harvest against applied P rates

Applied P	pH		Soil P, ppm		
(P_2O_5, kg/ha)	Before planting	After harvest	Before planting	After harvest	Difference
0	6.8	6.4	47.4	51.4	4
23	6.7	6.4	45.2	56.3	11.1
46	6.7	6.3	49.7	61.9	12.2
69	6.6	6.2	52.9	76.5	23.6
92	6.7	6.3	42.0	69.1	27.1

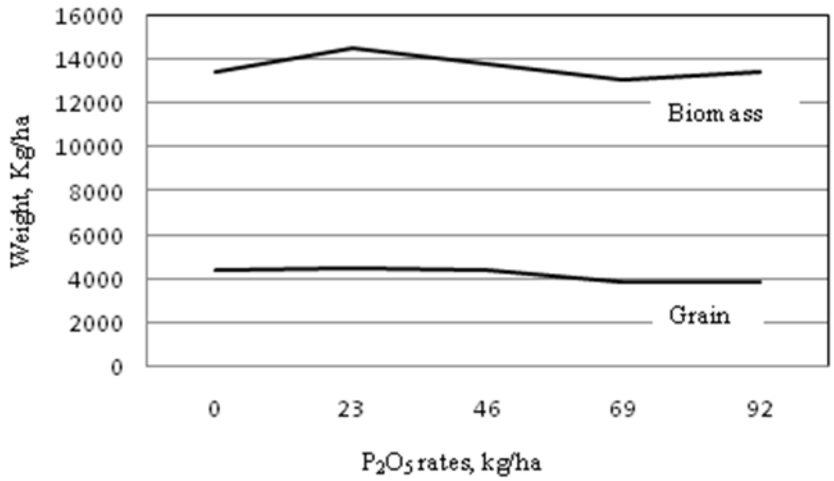

Fig. 1. Effect of applied P rates on grain yield and biomass weight

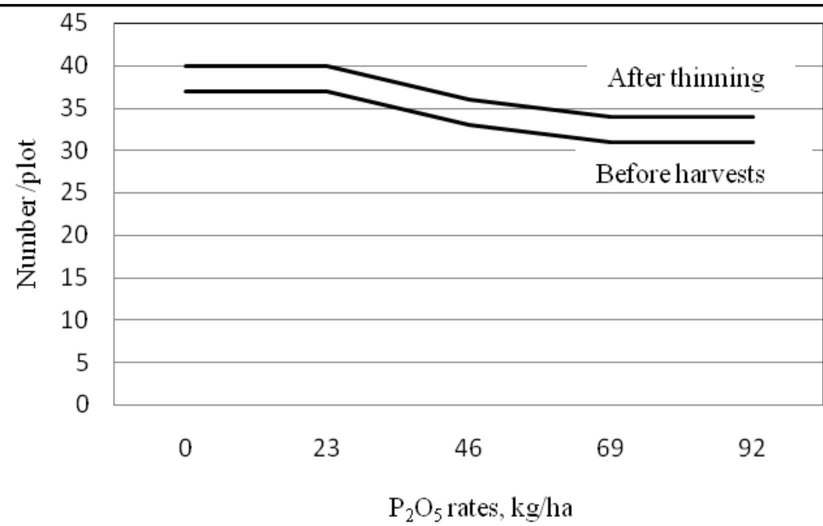

Fig. 2. Effect of applied P rates on stand count after thinning and before harvest

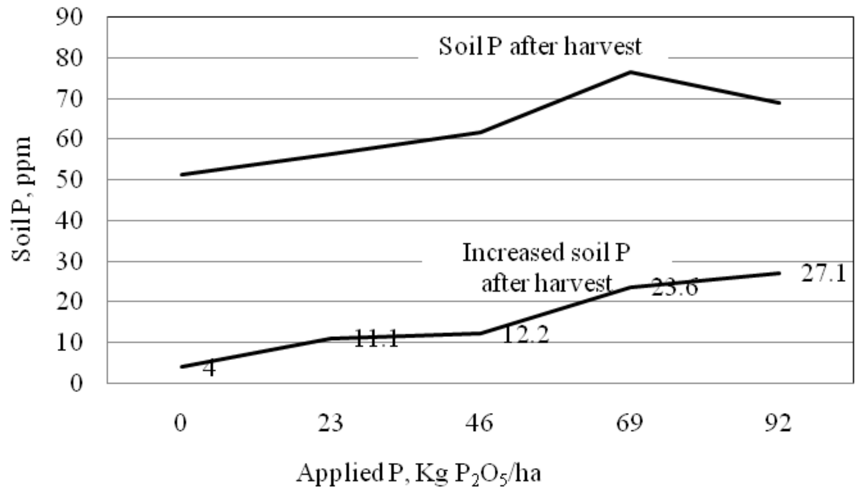

Fig 3. Soil P (ppm) after crop harvest as affected by applied P fertilizer

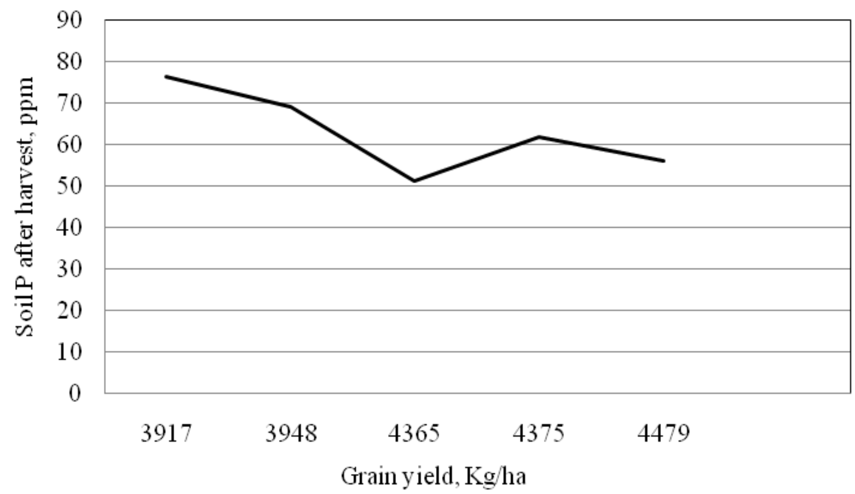

Fig 4. Relationship betwwen grain yield and soil P after harvest