Egypt. Acad. J. biolog. Sci., 1(1): 29-39(2010) **H. Botany**
Email: egyptianacademic@yahoo.com **ISSN 2090-3812**
Received: 20/6/2010 **www.eajbs.eg.net**

Timing and Rate of Phosphorus Application Influence Maize Phenology, Yield and Profitability in Northwest Pakistan

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ABSTRACT

Phosphorus (P) is the second most important crop nutrient after nitrogen that increase productivity and profitability of maize (*Zea mays* L.) on P deficient soils of NWPF (North West Frontier Province), Pakistan. The objective of this study was to find out the best level and time of P application for higher maize (cv. Azam) productivity and profitability. Field experiment was conducted at the Research Farm of NWFP Agricultural University, Peshawar during summer 2005, consisting of five P application timings [40, 30, 20 and 10 days before sowing (DBS), at sowing and 15 days after sowing (DAS)] as main plots, and three P levels (30, 60 and 90 kg P ha^{-1}) as subplots. The highest level of P enhanced phenological development, and increased ear length, number of rows and grains ear^{-1}, grain weight, economic yield, shelling percentage, and net returns. Application of P at 10 DBS had marked increase in ear length, grain weight, grain yield, shelling percentage and net returns; while plots that received P at sowing time produced the highest number of rows and grains ear^{-1}. There was no much difference in the net returns when P was applied 10 DBS (22, 560 PKR ha^{-1}) or at sowing (21, 883 PKR ha^{-1}). It could be concluded from the study that application of 90 kg P ha^{-1} either at 10 DBS or at sowing time is necessary for profitable maize production in the study area.

Keywords: *Zea mays* L., maize, P levels and timing, phenology, yield components, grain yield and net returns

INTRODUCTION

Maize (*Zea mays* L.) is the second major cereal crop after wheat in the North-west Frontier Province (NWFP) of Pakistan, but its yield per unit area is very low (Amanullah *et al.*, 2009a). The soils of NWFP are generally low in organic matter (Shah *et al.*, 2003) and low to medium in available P (Bhatti *et al.*, 1998). These soils contain high calcium carbonate with pH ranging from 7 to 9. This high calcium activity coupled with high pH favors the formation of relatively insoluble dicalcium phosphate and tricalcium phosphates. Soils with high fixation capacity have higher demand for phosphatic fertilizer (Hussain and Haq, 2000). Phosphorus deficiency is invariably a common crop growth and yield-limiting factor in unfertilized soils, especially in soils high in calcium carbonate, which reduces P solubility (Ibrikci *et al.*, 2005). Factors that affect the availability of P to plants include: soil pH, soil texture, the amount of P applied, the presence of other elements - like iron, aluminum, manganese and calcium in the soil, microbial activity and the time of P application (Yash *et al.*, 1992).

Maize grain and biomass yields, number of rows and grains ear^{-1}, plant height and P uptake efficiency (PUE) of maize increased at high P level (Okalebo and Probert, 1992; Sahoo and Panda, 2001). The time of P application to a crop is very important because it affects P efficiency and crop yield. Rasheed and Iqbal (1995) reported that maize yield can be improved through balanced and timely use of P fertilizers. Phosphoric fertilizers applied much in advance of crop sowing are liable to increased P fixation, and its affectiveness declines with the time between application and the stage at which the crop is in a position to make use of nutrients (Phillips and Webb, 1971).

Fixation of P increased as the time of contact between soluble P and soil particles increased. Consequently, a more efficient utilization of P fertilizer obtained when applied shortly before sowing (Griffith, 1983). In soils that fix the applied P quickly, one large application, near sowing, may be adequate to reduce P fixation (Yash *et al.*, 1992). Nisar and Bhatti (1978) found that wheat yield increased by 16.9 % when P fertilizers were applied at first irrigation compared with that applied at sowing time. Qureshi (1978) recommended that P fertilizers should be top dressed with first irrigation rather than applied and incorporated in the soil at sowing time. Another study reported that P application at planting was more effective than late application and that the relative availability of P diminished as the time between P application and planting of crop increased (Malik *et al.*, 1978). In contrast, Rehman *et al.* (1983) reported that P fertilizer application to maize is more effective and profitable at sowing than late application.

Our recent research (Amanullah *et al.*, 2009 b) indicates that P is one of the most important factors affecting crop growth and yield of maize in NWFP. Application of different P-fertilizer sources increased plant height, leaf area, grain weight, grains ear^{-1}, grain and stover yields, shelling percentage and harvest index as compared with control (P not applied). Previous literature suggests that P levels and its timings of application affect P availability, consequently affecting plant growth and yield. Studies on the proper combination of levels and timings of application of P have not been extensively carried out. For sustainable crop production, research on level x timing of P management is indispensable in wheat-maize cropping systems. The present study was, therefore, conducted to determine the best level and timing of P application to improve maize growth, increase yield and net returns.

MATERIALS AND METHODS

Site Description

The experiment was conducted at the New Developmental Agriculture Research Farm of the NWFP Agricultural University, Peshawar, Pakistan during summer 2005. The experimental farm is located at 34.01^{o} N latitude, 71.35^{o} E longitude at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1600 km north of the Indian Ocean and has the continental type of climate. The research farm is irrigated by Warsak canal from river Kabul. Soil is silty clay loam, low in organic matter (0.87 %), extractable P (5.6 mg P kg^{-1}), exchangeable potassium (121 mg K kg^{-1}), and alkaline (pH 8.2) and is calcareous in nature. The soils of NWFP are Pedocals, which comprise a dry soil group with high concentrations of calcium carbonate and a low content of organic matter; they are characteristic of a land with low and erratic precipitation in the regions. The area is generally semiarid with mean annual rainfall ranges between 300 and 500 mm per year. Of which 60-70 % rainfall occurs during summer (July-September) called monsoon rains, and the remaining 30-40 % rainfall occurs in winter.

Experimentation

Field experiment was conducted in a randomized complete block (RCB) design in split-plot arrangement using four replications. A sub plot size of 19.6 m^2 with 7 rows, 70 cm apart and 4 m long with plant to plant distance of 20 cm was used. Five different timing of P application viz. 40, 30, 20 and 10 days before sowing (DBS), at sowing and 15 days after sowing (DAS) used as main plots and three P levels viz. 30, 60 and 90 kg ha^{-1} were kept in sub plots. Single super phosphate (18 % P_2O_5) was used as a source of P. Maize (*cv.* Azam) was sown with a seed rate of 30 kg ha^{-1} and the desired plant density of 70,000 plants ha^{-1} was maintained by thinning the crop one week after emergence. Basal dose of nitrogen at 120 kg N ha^{-1} and potassium at 90 kg K_2O ha^{-1} was applied to all treatment plots. Nitrogen was applied in three equal splits i.e. at V9 stage (many ear shoots were easily visible upon dissection) and at VT stage (last branch of the tassel was completely visible and the silks were not yet emerged). Potash in the form of potassium sulphate was applied at the time of sowing. Irrigation, tillage, weeding and all other agronomic practices were followed uniformly throughout the growing period.

Data were recorded on phenology (days to tasseling, silking and physiological maturity), and yield and yield components (ear length, number of rows per ear and number of grains per ear, and grain weight). Days to emergence were recorded by counting number of days from sowing till the time when 70 % emergence occurred in each sub plot. Data on days to tasseling was recorded when more than 50 % of plants in each treatment developed tassels. Days were counted from the date of sowing till the completion of more than 50 % tasseling. Data on days to silking was recorded when more than 50 % of plants in each treatment had developed silks. Days were counted form date of emergence till the completion of more than 50 % silking. Number of days to maturity was counted from sowing till the plants were fully matured.

From each treatment ten ears were selected and ear length and the numbers of rows and grains per ear were counted after threshing and then averaged. Grain weight was determined by weighing 1000 grains, randomly taken from the grain lot of each subplot. This was repeated thrice in order to calculate the average grain weight. At maturity four central rows from each subplot were harvested. Ears were dried, shelled and weighed. Grain yield was expressed in kg ha^{-1}.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) according to the methods described by Steel *et al.* (1996), and treatment means were compared using the least significant difference (LSD) at $p \leq 0.05$.

Economic Analysis

Gross returns and net returns (the value of the increased yield produced as a result of P-fertilizers applied, less the cost of P) were determined according to the procedures described by Bhatti (2006) and Amanullah *et al.* (2010). Production cost amounting to PKR 23,4500 ha^{-1} other than P used ha^{-1} includes seedbed preparation, land lease, seed, drill planting, N, K, irrigation, furadan for the control of stem borers, and labor used for various operations.

RESULTS AND DISCUSSIONS

Phenology

Early tasseling (52-53 days) was noted in plots receiving P at higher levels but tasseling was delayed to 55 days in plots that receiving a lower level of P (Table 1).

Early tasseling (51 days) was obtained in plots when P was applied 10 days before sowing (DBS) but delayed to 55 days in plots when P was applied 40 DBS. Regarding P levels into timing interaction (P x T), earlier tasseling of 50 days was noted in plots when the highest P level was applied 10 DBS compared with 58 days in plots where the lowest P level was applied 40 DBS. Days to silking and maturity was significantly affected by levels and time of P application but their interaction (P x T) had no significant effect on both silking and maturity.

Table 1: Days to tasseling of maize as affected by level and time of P application

P levels ($kg\ ha^{-1}$)	P application timings						
	40 DBS[z]	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Mean
30	58	56	56	52	54	54	55 a[y]
60	56	55	52	52	52	53	53 b
90	53	52	52	50	52	54	52 b
Mean	55 a	54 ab	53 cd	51 e	52 d	54 bc	

LSD value for P levels ($p \leq 0.05$) = 1.317
LSD value for P timing ($p \leq 0.05$) = 1.023
LSD value for P x T ($p \leq 0.05$) = 2.017
[z]DBS and DAS refer to days before sowing and days after sowing, respectively.
[y]Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

Earlier silking (58 days) was noted in plots receiving highest P level being at par with medium P level but silking was significantly delayed to 61 days in plots receiving lowest P level (Table 2).

Table 2: Days to silking of maize as affected by level and time of P application

P levels ($kg\ ha^{-1}$)	P application timings						
	40 DBS[z]	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Mean
30	65	63	62	59	59	61	61 a[y]
60	61	60	57	57	58	60	59 b
90	59	59	58	56	57	60	58 b
Mean	62 a	61 ab	59 bc	57 c	58 c	60 ab	

LSD value for P levels ($p \leq 0.05$) = 2.403
LSD value for P timing ($p \leq 0.05$) = 1.666
[z]DBS and DAS refer to days before sowing and days after sowing, respectively.
[y]Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

Phosphorus applied close to sowing induced early silking in maize compared with that applied too earliest of after sowing. Our results showed that silking was delayed to 62 days when P was applied 40 DBS compared with 57 days when P was applied 10 DBS. Likewise earlier maturity (102 days) was obtained in plots which receiving highest P level compared with 108 days obtained in plots receiving the lowest P. Days to maturity in plots with lowest and medium P levels were at par with each other (Table 3).

Table 3: Days to maturity of maize as affected by level and time of P application

P levels ($kg\ ha^{-1}$)	P application timings						
	40 DBS[z]	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Mean
30	111	110	108	106	105	108	108 a[y]
60	110	108	109	104	104	107	107 a
90	102	102	101	102	100	103	102 b
Mean	108 a	107 ab	106 ab	104 bc	103 c	106 ab	

LSD value for P levels ($p \leq 0.05$) = 4.362
LSD value for P timing ($p \leq 0.05$) = 3.066
[z]DBS and DAS refer to days before sowing and days after sowing, respectively.
[y]Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

Phosphorus application at sowing enhanced crop maturity by six days compared with that applied 40 DBS. Enhancement in the phenological development of maize with higher rate of P may probably have increased root development and thus helped the plants obtained more P to complete its life cycle earlier. Rapid plant growth and development with the highest rate of P was also earlier reported by Singaram and Kothandaraman (1994). Tasseling, silking and maturity period enhanced when P was applied close to sowing (10 DBS) compared with that applied too earlier P application (40 DBS). The delay in phenological development of maize with earlier P application might be due to the increased fixation of P in soil as the time of contact between soluble P and soil particles increased with such that decreased P availability to plants. On the other hand, earlier phenological development in maize with P applied close to sowing (10 DBS) or at the time of sowing might be due to efficient utilization of P by plants (Griffith, 1983). The high pH (8.2) of the experimental site might have caused increased P fixation in soil with earlier P application (40 DBS). Yash *et al.* (1992) suggested that high pH soils adversely affect P availability to plants so P should be applied close to sowing to reduced P fixation**.**

Yield components

Levels and time of P application had significant effects on ear length, number of rows, grains per ear, and grain weight of maize. The longest ears of 23.29 cm were produced with highest level of P compared with 17.58 cm produced with the lowest P level (Table 4). As regards time of application, P application close to sowing produced significantly longest ears compared with that applied too earlier or after sowing. Our results showed that longest ears of 23.08 cm length were recorded in plots receiving P 10 DBS compared with 18.42 cm length obtained in plots receiving P 40 DBS. The effect of the latter was comparable with that of 30 and 20 DBS. The ears length in maize showed positive response to increasing levels of P. The reason for increased length of ear of maize due to higher level of P could be that higher translocation of assimilates as well as of P into ears have accrued and have been resulted into increased ear lengths. Sahoo and Panda (2001) also reported that length of ears increased with increasing level of P. We observed that P application close to sowing produced longest ears of maize. The earlier application of P might have reduced P availability and its uptake by maize and have been resulted in shortest ears. The increase in ear length of maize with P application close to sowing probably may be due to increased in number of leaves per plant and, mean leaf area (Amanullah *et al.*, 2009b).

Table 4: Ear length (cm) of maize as affected by level and time of P application

P levels (kg ha^{-1})	P application timings						
	40 DBS^{z}	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Mean
30	15.50	15.50	16.00	20.50	19.50	18.50	17.58c^{y}
60	18.25	19.25	18.00	23.00	22.25	21.25	20.33b
90	21.50	22.25	22.25	25.75	24.50	23.75	23.29a
Mean	18.42c	19.00c	18.75c	23.08a	22.00ab	21.17b	

LSD value for P levels ($p \leq 0.05$) = 2.308
LSD value for P timing ($p \leq 0.05$) = 1.115
^{z}DBS and DAS refer to days before sowing and days after sowing, respectively.
^{y}Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

Maximum of 15.50 rows ear^{-1} of maize were recorded in plots receiving the highest P level compared with 13.50 rows ear^{-1} obtained in plots receiving the lowest P level (Table 5). The significantly highest number of 18.17 rows ear^{-1} were obtained when P was applied at sowing compared with 12.50 rows ear^{-1} obtained when P was applied 40 DBS. The effect of the latter was at par with that of 30 and 20 DBS. Similarly, the highest number of 378 grains ear^{-1} were recorded in plots with 90 kg P ha^{-1} compared with 343 grains ear^{-1} obtained in plots that receiving 30 kg P ha^{-1} (Table 6). The effect of levels of P on number of grains differed significantly from one another. Significantly highest number of 370 grains ear^{-1} were recorded in the plot that receiving P 10 DBS compared with 353 grains ear^{-1} obtained in plots that received P 40 DBS, the effect of the latter was at par with that of 30 and 20 DBS. The number of rows and the number of grains per ear of maize increased with increasing levels of P application.

Table 5: Number of rows ear^{-1} of maize as affected by level and time of P application

P levels (kg ha^{-1})	P application timings						
	40 DBS[z]	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Means
30	12.00	11.00	13.50	14.50	17.00	13.00	13.50b[y]
60	13.00	13.00	13.00	15.00	18.50	14.50	14.50ab
90	12.50	14.50	14.50	16.50	19.00	16.00	15.50a
Mean	12.50d	12.83d	13.67cd	15.33b	18.17a	14.50bc	

LSD value for P levels ($p \leq 0.05$) = 1.942
LSD value for P timing ($p \leq 0.05$) = 1.393
[z]DBS and DAS refer to days before sowing and days after sowing, respectively.
[y]Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

Table 6: Grains ear^{-1} of maize as affected by level and time of P application

P levels (kg ha^{-1})	P application timings						
	40 DBS[z]	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Mean
30	340	338	338	345	355	348	344 c[y]
60	346	351	357	360	368	359	357 b
90	372	373	374	379	388	381	378 a
Mean	353 c	354 c	356 c	362 b	370 a	362 b	

LSD value for P levels ($p \leq 0.05$) = 6.727
LSD value for P timing ($p \leq 0.05$) = 4.946
[z]DBS and DAS refer to days before sowing and days after sowing, respectively.
[y]Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

The possible reason could be that higher P level might have resulted in greater assimilates partitioning to the ears which increased the number of rows and the number of grains per ear compared with that obtained with the lower P level. Okalebo and Probert (1992) also reported that number of grains and the number of rows per ear increased with increasing levels of P. The number of rows and the number of were decreased when P was applied too earlier to sowing compared with that applied close to sowing. The decrease in the number of rows and the number of grains per ear, with earlier P application, might be due to increased in P-fixation in soil as the time of contact between fertilizer P and soil particles increased and P-availability to plants reduced. The increase in the number of rows and the number of grains per ear, with the application of the highest level of 90 kg P ha^{-1} at 10 DBS or at sowing could be attributed mainly to increased number of leaves, increased leaf area and increased dry weight of ears.

The highest thousand grain weight of 213.30 g was obtained from plots receiving the highest level of P compared with 175.80 g obtained in plots receiving the lowest P level (Table 7). The effect of all the three P levels on 1000-grain weight differed significantly from one another. The highest thousand grain weight of 205.6 g was recorded in plots that receiving P at sowing compared with 184.3 g obtained in plots that received P 40 DBS, which was statistically similar to that received P at 30

DBS. Heaviest grain weight with higher P level probably may be due to the higher P translocation into the fruiting areas which resulted in highest grain weight (Amanullah *et al.*, 2009b). Sahoo and Panda (2001) also suggested that increase in P levels increased grain weight in maize. Grain weight of maize increased when P was applied at sowing than applied earlier. Because of silty clay or silty clay loam nature of soil texture of the experimental site, P availability might have decreased when applied much earlier of sowing time. Roman and Willium (1993) found that clay loam texture soils had maximum P fixation. Increase in the seed weight of maize when applied with the highest level of 90 kg P ha^{-1} at 10 DBS or at sowing probably may be due increased number of leaves per plant, leaf area and ear dry weight.

Table 7: Thousand grain weight (g) of maize as affected by level and time of P application

P levels ($kg\ ha^{-1}$)	P application timings						
	40 DBS[z]	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Mean
30	168.00	171.00	174.25	178.25	186.25	176.75	175.8c[y]
60	183.75	189.75	192.25	195.25	204.75	195.50	193.2b
90	201.25	206.50	211.75	217.75	225.75	216.75	213.3a
Mean	184.3d	188.1cd	192.8bc	197.10b	205.60a	196.70b	

LSD value for P levels ($p \leq 0.05$) = 7.104
LSD value for P timing ($p \leq 0.05$) = 6.153
[z]DBS and DAS refer to days before sowing and days after sowing, respectively.
[y]Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

Grain yield and shelling percentage

Levels and time of P application had significant effect on both grain yield (Table 8) and shelling percentage (Table 9) of maize, but the effect of their interaction on grain yield and shelling percentage was not significant ($p \leq 0.05$). The significantly highest grain yield of 2164 kg ha^{-1} and shelling percentage of 85.38 % was obtained with the highest P level being applied (90 kg ha^{-1}) compared 1666 kg ha^{-1} and 74.46 %, respectively obtained with the lowest P level (30 kg ha^{-1}). The effect of all these levels of P on grain yield and shelling percentage differed significantly from one another.

Table 8: Grain yield ($kg\ ha^{-1}$) of maize as affected by level and time of P application

P levels ($kg\ ha^{-1}$)	P application timings						
	40 DBS[z]	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Mean
30	1635	1641	1669	1697	1691	1660	1666 c[y]
60	1899	1912	1936	2001	1972	1947	1945 b
90	2092	2110	2146	2268	2215	2154	2164 a
Mean	1876 c	1888 bc	1917 b	1989 a	1959 a	1920 b	

LSD value for P levels ($p \leq 0.05$) = 150.00
LSD value for P timing ($p \leq 0.05$) = 38.63
[z]DBS and DAS refer to days before sowing and days after sowing, respectively.
[y]Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

Table 9: Shelling percentage (%) of maize as affected by level and time of P application

P_2O_5 levels ($kg\ ha^{-1}$)	P application timings						
	40 DBS[z]	30 DBS	20 DBS	10 DBS	At sowing	15 DAS	Mean
30	64.50	73.50	73.75	81.00	78.25	74.50	74.85b[y]
60	65.25	65.25	69.25	74.25	74.00	80.75	71.46b
90	81.75	832.50	85.25	90.25	88.50	83.00	85.38a
Mean	70.50c	74.08bc	76.08abc	81.83a	80.25ab	79.42ab	

LSD value for P levels ($p \leq 0.05$) = 14.20
LSD value for P timing ($p \leq 0.05$) = 6.246
[z]DBS and DAS refer to days before sowing and days after sowing, respectively.
[y]Mean values of the same category followed by different letters are significant at $P \leq 0.05$ using LSD.

As regards time of P application, the highest grain yield of 1989 kg ha^{-1} and shelling percentage of 81.83 % was obtained in plots that receiving P 10 DBS which was statistically similar to plots receiving P at the time of sowing. The lowest grain yield (1876 kg ha^{-1}) and the lowest shelling percentage (70.50 %) were obtained, when P was applied 40 DBS, which was statistically similar to plots receiving P 30 DBS.

Phosphorus application at 90 kg P ha^{-1} resulted in a marked increase in grain yield and shelling percentage. The increase in maize yield and shelling percentage with increase in P level probably may be due to the increase in ear-length, number of rows and number of grains per ear as well as heaviest grain weight (Amanullah *et al.*, 2009b). The lower grain yield and shelling percentage in the absence of P (control) indicating higher demand for P fertilizer (Hussanin and Haq, 2000). Ibrikci *et al.* (2005) suggested that P deficiency was invariably a common crop growth and yield-limiting factor, especially in soils high in calcium carbonate, which reduces P solubility. The higher grain yield and shelling percentage of maize with P application close to sowing time might be due to higher pool of available P as fertilizer P had less chance for P fixation. These findings are in agreement with that of Griffith (1983) who reported that P fixation in soil increased when time-period of contact between soluble-P and soil particles increased. Nisar and Bhatti (1978) reported 16.9 % increase in wheat yield when P fertilizers were applied with first irrigation compared with that applied at sowing time. The lower grain yield and shelling percentage with earlier P application (40 DBS) might have increased P retention and decreased its availability because of longer soil and added-P contact, which would have a negative impact on the normal growth of the crop, consequently resulting into a delaying phenology, as well as a reduced grain yield and a lower shelling percentage. Late application of P 15 DAE (days after emergence) delayed phenology, and significantly reduced grain yield and shelling percentage, indicating that the crop was subjected to P-deficiency during the early growth stage. Therefore, phosphorus should be applied 10 days before sowing or at the time of sowing to the short duration crops, like maize etc. because P requirement is high in the early plant growth and because P fertilizers release P very slowly for the growth of the crop. These results support the idea of Rashid *et al.* (1988) that two-week time is required for the establishment of equilibrium after the addition of P fertilizer to the alkaline calcareous soils of Pakistan.

Profitability

Increase in P level had a positive impact on grain and stover yields as well as net returns (Table 10). Net returns increased by 22,089 and 23,640 PKR ha^{-1} with application of 60 and 90 kg P ha^{-1}, respectively as compared with 30 kg P ha^{-1}. Net returns from maize crop increased by 27 % when P was applied at a higher (90 kg P ha^{-1}) than the lower rate (30 kg P ha^{-1}), and increased by about 7 % when P was applied at a higher than the recommended rate (60 kg P ha^{-1}). The increase in net return with higher P rate was probably due to the higher stover and grain yields than lower P rates. Hussain and Haq (2000) reported that high calcium activity coupled with high pH favors the formation of relatively insoluble dicalcium phosphate and tricalcium phosphates in soils of NWFP, therefore, have higher demand for P fertilizer. Phosphorus applied 10 DBS or at sowing had significantly higher grain and stover yields in maize. Similarly, net returns from maize crop increased tremendously when P was applied 10 DBS (22,567 PKR ha^{-1}) and at sowing time (22,567 PKR ha^{-1}) as compared with other P timings. Yash *et al.* (1992) suggested that high pH soils adversely affect P availability to plants so P should be applied close to sowing to reduced P fixation. Too early and late application of P declined net returns. Phosphorus applied at 10 DBS was 13, 11, and 8 % more economical in terms of net returns as compared to P applied at 40, 30 and 20 DBS, respectively. Earlier P application may probably increase P-fixation with more time of contact between soluble P and soil particles.

Table 10: Profitability of maize as affected by level and time of P application

P Level (kg ha^{-1})	Grain Yield	Value of GY	Stover Yield	Value of SY	Gross Returns	Cost of P	Other Cost	Total Cost	Net Returns
30	1666	39984	2696	2696	42680	2010	23450	25460	17220
60	1945	46680	2879	2879	49559	4020	23450	27470	22089
90	2164	51936	3194	3194	55130	8040	23450	31490	23640
P Timing									
40 DBS	1876	45024	2856	2856	47880	4690	23450	28140	19740
30 DBS	1888	45312	2883	2883	48195	4690	23450	28140	20055
20 DBS	1917	46008	2907	2907	48915	4690	23450	28140	20775
10 DBS	1989	47736	2971	2971	50707	4690	23450	28140	22567
0 DBS	1959	47016	3007	3007	50023	4690	23450	28140	21883
15 DAS	1920	46080	2913	2913	48993	4690	23450	28140	20853

Where DBS stands for days before sowing and DAS stands for days after sowing One US dollar is equal to 80 Pakistani rupees.

Consequently, more efficient utilization of P was generally obtained by applying the fertilizer P at 10 DBS of maize crop. As soils of NWFP generally had more P-fixing capacity (Hussain and Haq, 2000), therefore, too early P application was not economical in the current study. Phosphoric fertilizers applied much in advance of crop sowing are liable to increased P-fixation, and its effectiveness declines with the time between application and the stage at which the crop is in a position to make use of nutrients (Phillips and Webb, 1971). Phosphorus applied at 10 DBS resulted in 3 % higher net returns as compared to P applied at the time of sowing. Further delay of P application after maize emergence was also not economical as compared with P applied 10 DBS and at sowing time. Phosphorus applied 15 days after sowing resulted in 5 and 8 % less net returns compared to P applied at time of sowing and 10 DBS, respectively. Rehman *et al.* (1983) reported that P fertilizer application to maize is more effective and profitable at sowing than late application. In contrast to our result, Qureshi (1978) recommended that P fertilizers should be top dressed with first irrigation rather than applied and incorporated in the soil at sowing time. The difference in the results obtained in our current study and that of Qureshi (1978) wast. Cisse and Amar (2000) suggested that application of essential plant nutrients in optimum quantity and proper time of application is the key to increased and sustained crop productivity and profitability.

CONCLUSIONS

Our findings suggest that higher rate of phosphorus (90 kg P ha^{-1}) applied either at sowing or 10 days before sowing had the maximum positive impact on maize growth, yield and profitability in Northwest Pakistan. The farmers of NWFP who apply very less or no P to maize crop, require demonstration of the benefits of the higher P level that should be applied about 10 days before sowing or at sowing. Application of 50 % higher P rate (90 kg P ha^{-1}) could be more profitable than the recommended rate of 60 kg P ha^{-1} in the study area. Further research work for understanding the impacts of P levels x timing for high sustainable crop production in different agro-ecological zones of NWFP is also suggested.

ACKNOWLEDGEMENTS

Financial support from NWFP Agricultural University Peshawar for this research project is greatly acknowledged.

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