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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 increases productivity and profitability of maize (*Zea mays* L.) on P deficient soils in Northwest Pakistan. The objective of this study was to find 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 Khyber Pakhtunkhwa Agricultural University, Peshawar during summer 2005, comprising of six 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 at 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 Khyber Pakhtunkhwa (KPK) Province of Pakistan, but its yield per unit area is very low (Amanullah et al., 2009a). The soils of KPK 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). In West Africa P-deficiency is a major constraint to crop production on highly weathered, low activity clay soils in the humid zone (Sahrawat, 2008). Genotypes showed significant differences in chlorophyll meter reading, number of tillers, shoot P concentration and content (the total amount of P per shoot in pot), and shoot dry weight when applied with variable rates of P (Sepehr et al., 2009).

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., 2009b) indicates that P is one of the most important factors affecting growth and yield of maize in KPK. 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 levels into 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 KPK 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 continental type of climate. The research farm is irrigated by Warsak canal from Kabul River. Soil is silty clay loam, low in organic matter (0.87%), extractable P (5.6 mg P kg^{-1}) and exchangeable potassium (121 mg K kg^{-1}), alkaline (pH 8.2) and is calcareous in nature. Most of the soils in KPK 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 (Amanullah et al., 2009b).

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. Six 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 sowing, 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). Potassium 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. A total of seven irrigations were applied to the maize crop in the growing season.

Data were recorded on phenology (days to tasseling, silking and physiological maturity), grain yield and yield components (ear length, number of rows per ear and number of grains per ear, and grain weight). Date on which about 75% plants reached tasseling stage was recorded for each experimental unit and then days to tasseling were calculated as difference between date of tasseling and date of emergence. Date on which 75% plants reached silking stage was recorded for each experimental unit and then days to silking was calculated as difference between date of silking and date of emergence. Appearance of black layer in seeds was used as criteria for physiological maturity. Days to physiological maturity was calculated as difference between date of physiological maturity and date of emergence (Amanullah et al., 2009a). 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 the plots that received P at higher levels, and delayed significantly (55 days) in plots applied with lower level of P (Table 1). Early tasseling (51 days) was obtained in plots when P was applied at 10 days before sowing (DBS) and delayed to 55 days in plots when P was applied at 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 at 10 DBS compared with 58 days in plots where the lowest P level was applied at 40 DBS. Days to silking and physiological maturity was significantly affected by levels and P application time, but their interaction (P x T) had no significant effect on both silking and physiological maturity. Earlier silking (58 days) was noted in plots that received the highest P level being at par with medium P level, and significantly delayed to 61 days in plots applied with the lowest P level (Table 2). Phosphorus applied close to sowing induced early silking in maize compared with that applied either too early or too late. Silking was delayed to 62 days when P was applied at 40 DBS compared with 57 days when P was applied at 10 DBS. Likewise, earlier physiological maturity (102 days) was obtained in plots which received the highest P level compared with 108 days obtained in plots applied with the lowest P level. Days to physiological maturity was statistically the same in the plots applied with the lowest and medium P levels (Table 3). Phosphorus application at sowing time enhanced crop maturity by six days compared to P applied at 40 DBS. The early phenological development in maize with higher P level may probably have increased root development and thus helped the plants to obtain more P to complete its life cycle quickly. Rapid plant growth and development with the highest rate of P was also earlier reported by Singaram and Kothandaraman (1994). The delay in phenological development in maize with too early 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 maize plants. On the other hand, early 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 maize plants (Griffith, 1983). The high pH (8.2) of the experimental site might have caused increased P fixation in soil with too early 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.

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^{ay}
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≤0.05) = 1.317.
LSD value for P timing (P≤0.05) = 1.023.
LSD value for P x T (P≤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≤0.05 using LSD.

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^{ay}
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≤0.05) = 2.403.
LSD value for P timing (P≤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≤0.05 using LSD.

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^{ay}
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≤0.05) = 4.362.
LSD value for P timing (P≤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≤0.05 using LSD.

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 (23.29 cm) were produced with highest P level as compared with 17.58 cm produced with the lowest P level (Table 4). Ear length showed positive response to increasing levels of P. The higher P level might have translocated higher amount of assimilates into ears that have been resulted into longer ears.

Sahoo and Panda (2001) reported that ear length increased with increasing P level. Among P application timings, P applied close to sowing produced significantly the longest ears compared with that applied too earlier or after sowing. The longest ears (23.08 cm) were recorded in plots that received P at 10 DBS compared to 18.42 cm ears length noted in plots applied with P at 40 DBS. 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 the increase 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	17.58[cy]
60	18.25	19.25	18.00	23.00	22.25	21.25	20.33[b]
90	21.50	22.25	22.25	25.75	24.50	23.75	23.29[a]
Mean	18.42[c]	19.00[c]	18.75[c]	23.08[a]	22.00[ab]	21.17[b]	

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 was recorded in plots that received the highest P level compared to the minimum of 13.50 rows ear^{-1} obtained in plots applied with the lowest P level (Table 5). The highest number of 18.17 rows ear^{-1} was obtained when P was applied at sowing compared with 12.50 rows ear^{-1} obtained when P was applied at 40 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). Among P application timings, the highest number of 370 grains ear^{-1} were recorded in the plot that received P at 10 DBS compared with the lowest number of 353 grains ear^{-1} obtained in plots that received P at 40 DBS. The increase in P level might have partitioned greater amount of assimilates to ears which resulted in the highest number of rows and grains per ear of maize (Okalebo and Probert, 1992). The number of rows and grains per ear decreased significantly when P was applied too earlier than close to sowing. The earlier applied P might have increased P-fixation in the soil as the time of contact between fertilizer P and soil particles increased which delined P availability that resulted in the lower number of rows and grains per ear in maize.

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	13.50[by]
60	13.00	13.00	13.00	15.00	18.50	14.50	14.50[ab]
90	12.50	14.50	14.50	16.50	19.00	16.00	15.50[a]
Mean	12.50[d]	12.83[d]	13.67[cd]	15.33[b]	18.17[a]	14.50[bc]	

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[cy]
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≤0.05) = 6.727.
LSD value for P timing (P≤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≤0.05 using LSD.

The highest thousand grains weight (213.30 g/1000 grains) was noted for the plots that received the highest P level as compared with the lowest weight (175.80 g/1000 grains) for those plots applied with the lowest P level (Table 7). The highest grain weight of maize with higher P level probably may be due to the higher P translocation into the ears which resulted in heaviest grains (Sahoo and Panda, 2001). Among P application timings, the highest thousand grains weight (205.6 g) was recorded in plots that received P at sowing time and the lowest weight (184.3 g/1000 grains) was noted in the plots that received P at 40 DBS being at par with 30 DBS. Because of the silty clay loam nature of soil texture of the experimental site, P availability might have decreased when P was applied much earlier of sowing time (Roman and Willium, 1993). Application of the highest level of 90 kg P ha^{-1} at 10 DBS or at sowing increased number of leaves and leaf area per plant as well as ear dry weight (unpublished data) that could be the possible reasen for higher number of rows and grains per ear, and grains weight. Amanullah et al. (2009b) reported increase in leaf area, grains per ear and grains weight with application of different P-fertilizer than control (P not applied).

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	175.8[cy]
60	183.75	189.75	192.25	195.25	204.75	195.50	193.2[b]
90	201.25	206.50	211.75	217.75	225.75	216.75	213.3[a]
Mean	184.3[d]	188.1[cd]	192.8b[c]	197.10[b]	205.60[a]	196.70[b]	

LSD value for P levels (P≤0.05) = 7.104.
LSD value for P timing (P≤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≤0.05 using LSD.

Grain yield and shelling percentage

Levels and time of P application had significant effects on grain yield (Table 8) and shelling percentage (Table 9), but their interaction had no significant effects on grain yield and shelling percentage (P≤0.05). The highest grain yield (2164 kg ha^{-1}) and shelling percentage (85.38%) was obtained with application of the highest P level (90 kg ha^{-1}) when compared to the lowest grain yield (1666 kg ha^{-1}) and shelling percentage (74.46%) obtained in the plots applied with the lowest P level (30 kg ha^{-1}). Among the six P application timings, the highest grain yield (1989 kg ha^{-1}) and shelling percentage (81.83%) was obtained in plots that received P 10 days before sowing which was statistically similar to the grain yield obtained from the plots that received P at sowing time. The lowest grain yield (1876 kg ha^{-1}) and shelling percentage (70.50%) was obtained when P was applied at 40 DBS, which was statistically similar to the yield in the plots that received P at 30 DBS.

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[cy]
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≤0.05) = 150.00.
LSD value for P timing (P≤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 ≤ 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	74.85[by]
60	65.25	65.25	69.25	74.25	74.00	80.75	71.46[b]
90	81.75	832.50	85.25	90.25	88.50	83.00	85.38[a]
Mean	70.50c	74.08bc	76.08[abc]	81.83[a]	80.25[ab]	79.42[ab]	

LSD value for P levels (P≤0.05) = 14.20.
LSD value for P timing (P≤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≤0.05 using LSD.

Phosphorus application at the rate of 90 kg P ha^{-1} resulted in a marked increase in both 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 grains weight (Amanullah et al., 2009b). The lower grain yield and shelling percentage in the absence or lower P rate indicating higher demand for P fertilizer (Hussanin and Haq, 2000). Ibrikci et al. (2005) suggested that P deficiency is 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 had a less chance for P fixation. These findings are in agreement with those 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 at 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 at 10 DBS or at sowing to the short duration maizecrop 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 yield as well as net returns (Table 10). Net returns increased by 22,089 and 23,640 PKR (Pakistani Rupees) ha^{-1} (85 PKR = 1 USD) 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 increase in yield components and higher grain yield than lower P rates. Amanullah et al. (2010) suggested positive relationship between maize grain yield and net returns. 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 KPK, therefore, have higher demand for P fertilizer. Phosphorus applied at 10 DBS or at sowing had significantly higher grain yield, and therefore, net returns increased tremendously to 22,567 PKR ha^{-1} when P was applied at 10 DBS or at sowing time (21883 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. 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. Consequently, more efficient utilization of P was generally obtained by applying the fertilizer P at 10 DBS of maize crop. As soils of KPK 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 at 10 DBS and at sowing time. Phosphorus applied at 15 days after sowing resulted in 5 and 8% less net returns compared to P applied at time of sowing and at 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. 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.

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 85 Pakistani Rupees (PKR).

Conclusions

Our findings suggest that higher rate of phosphorus (90 kg P ha^{-1}) applied either at sowing or at 10 days before sowing had the maximum positive impact on maize growth, yield and profitability in Northwest Pakistan. The farmers of KPK 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 studies are underway to illustrate P mangement for high sustainable and profitable maize production in the study area.

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