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□ *The use of appropriate source of phosphorus (P) fertilizer at different planting densities has considerable impact on growth, grain yield as well as profitability of maize (*Zea mays *L). Field experiment was conducted in order to investigate the impact of P sources [(S_0 = P not applied, S_1 = SSP (single super phosphate) S_2 = NP (nitrophos), and S_3 = DAP (diammonium phosphate)] on maize growth analysis, yield and economic returns planted at different planting densities (D_1 = 40,000, D_2 = 60,000, D_3 = 80,000, and D_4 = 100,000 plants ha^{-1}) at the New Developmental Agricultural Research Farm of Khyber Pakhtunkhwa Agricultural University, Peshawar, Pakistan, during summer 2006. This paper reports the profitability data with two objectives: 1) to compare agronomic efficiency and profitability of P-fertilizers, and 2) to know whether plant densities affect agronomic efficiency and profitability of P-fertilizers. Application of DAP and SSP resulted in higher partial factor productivity (PFP) (63.58 and 61.92 kg grains kg^{-1} P), agronomic efficiency (AE) (13.01 and 13.71 kg grains kg^{-1} P) and net returns (NR) (Rs. 16,289 and 16,204 ha^{-1}), respectively, while NP stood at the bottom in the ranking with lower PFP (57.16 kg grains kg^{-1} P), AE (8.94 kg grains kg^{-1} P) and NR (Rs. 4,472 ha^{-1}). Among the plant densities, D_3 stood first with maximum PFP (69.60 kg grains kg^{-1} P), AE (18.21 kg grains kg^{-1} P) and NR (Rs. 21,461 ha^{-1}) as compared to other plant densities. In conclusion, the findings suggest that growing maize at D_3 applied with either SSP or DAP is more profitable in the wheat-maize cropping system in the study area.*

Keywords: maize, *Zea mays* L., planting density, P-fertilizers, agronomic efficiency, net returns

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INTRODUCTION

Maize (*Zea mays* L.) is the second most important crop after wheat in the Khyber Pakhtunkhwa Province of Pakistan but its yield per unit area is very low. In Pakistan wheat is the major crop on which phosphorus is applied (55%), followed by cotton (24%), sugar cane and rice 7% each, but the share of maize in phosphorus (P) is just 1.5% (NFDC, 2005). The average yield in the Punjab province (4289 kg ha^{-1}) was far better than that of Khyber Pakhtunkhwa (1590 kg ha^{-1}) during 2005-06 growing season (Anonymous, 2007). This appreciable difference in maize production in Punjab over Khyber Pakhtunkhwa was due to adoption of hybrid maize by the farmers that resulted 28.2% increase in yield in Punjab, on the other hand in Khyber Pakhtunkhwa that was the leading maize producing province in the recent past reduced its yield by minus 7.1% in 2005–2006 as compared to 2004–2005. During 2005–2006, in overall nutrient uptake Punjab's share was 69.2%, Sindh 22.7%, Khyber Pakhtunkhwa 6.3% and Baluchistan 2.6%. Overall nutrient consumption in Punjab province increased by 3.9%, Sindh by 0.7%, Baluchistan by 12%, while Khyber Pakhtunkhwa consumption of nutrient decreased by 3.3% in 2005–2006 as compared to 2004–2005. The increase in consumption of N offtake (+ 4.7%) against decrease in phosphate offtake (-1.6%) reduced nitrogen (N): P ratio from 3.23 in 2004–2005 to 3.44 during 2005–2006 (NFDC, 2005).

Efficient fertilizer use can be defined as maximum returns per unit of fertilizer applied (Mortvedt et al., 2001). Judicious use of P-fertilizer is a key factor in the cereals based system of Pakistan for sustainable agriculture. Imbalanced fertilizer use especially in terms of phosphate (P) compared with N, has created concern in Pakistan as it may affect overall agricultural productivity and economic growth (FAO, 2007). In many developing countries N use, in relation to P and potassium (K) use, is excessive (Bumb et al., 1996). Low P-utilization efficiency by crops under existing soil conditions and low use of phosphatic fertilizers may be the main reason for this wide ratio. The soils of Khyber Pakhtunkhwa have low organic matter content and low to medium available P. These soils contain high calcium carbonate ($CaCO_3$) with pH ranging from 7 to 9. This high calcium activity coupled with high pH favors the formation of relatively insoluble dicalcium phosphate, hydroxyl apatite, carbonate apatite, and octo calcium phosphate. 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). In soils having high P-fixation tendency, low grade fertilizers are found to be less efficient because of their higher exposure to soil mass. High grade P-fertilizers, on the other hand, may yield higher utilization efficiency if properly applied.

The selection of fertilizers commonly depends upon price: the least costly fertilizer per kilogram of plant food is the one commonly selected (Plaster, 1992). Farmers in Pakistan are profit-oriented, and therefore, they are interested in net returns than the gross returns. In practice, not all farmers, however, can aim for the largest net return because of the generally larger costs involved to other risks associated with farming (Saleem et al., 1986). To increase yields and profits, fertilizers, along with improved farming practices are the best investments farmers can make. Ali et al. (2007) reported variation in net return (Rs. 33828-84096 ha^{-1}) when wheat was grown with different fertilizers treatments. Similarly, Haq et al. (2007) found significant variation in net return (Rs. 111-60991 ha^{-1}) with different gypsum and farm yard manure combination applied to sugar cane. Saleem et al. (1986) reported variation of Rs. 720-2045 ha^{-1} in net returns from wheat applied with different N-P-K combination. On the other hand a variation of Rs. 1680-3669 ha^{-1} in net returns from wheat applied with different N-P-K combination was reported by Bhatti (2006). According to Yadav (2003) partial factor productivity (PFP) and agronomic efficiency is a useful measure of nutrient use efficiency as it provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system. According to Cassman et al. (1996), PFP and AE can be increased by increasing the amount, uptake and utilization of available nutrients, and by increasing the efficiency with which applied nutrients are taken up by the crop and utilized to produce grain.

Application of a unit fertilizer is economical, if the value of the increase in the crop yield due to the quantity of fertilizer added is greater than the cost of fertilizer used. If a unit of fertilizer does not increase the yield enough to pay for its cost, its application will not be economical and will not return profit even after a constant increase in the yield (Singh, 2004). The application of essential plant nutrients in optimum quantity and right proportion, through correct method and time of application, is the key to increased and sustained crop production (Cisse and Amar, 2000). Grain and biomass yields, number of grains ear^{-1} and number of rows ear^{-1}, plant height and P uptake efficiency (PUE) of maize increases at high level of P application (Okalebo and Probert, 1992; Sahoo and Panda, 2001). Reduction in number of adventitious roots on P-deficient maize plants is caused by the negative effect of P deficiency on LAI and its subsequent effect on PAR absorption and C nutrition of plants (Pellerin et al., 2000). Reduced LAI in maize is the consequence both of the delayed appearance of leaves on P-deficient plants and of a reduction of their final surface area (Plenet et al., 2000b). Plenet et al. (2000a) showed that the lower biomass accumulation in the P deficient plants is mainly explained by this effect of P deficiency on leaf growth and its subsequent effect on PAR absorption.

But, previous research has shown no clear-cut superiority of one P fertilizer source over the other when applied at the same dosages of N and

P. For example, in western Nigeria, there were no significant differences in maize yield with application of single super phosphate (SSP), TSP (triplesuperphosphate), NP (nitrophos), and DAP (diammonium phosphate) (Osinama, 1995). In other research studies, DAP was found more efficient source of P than SSP and TSP in increasing maize grain yield in India (Reghurum et al., 1994), and leaf area plant^{-1} when compared with NP in western Nigeria (Singh, 1984). In some cases TSP gave higher yield than DAP, but in other cases it produced lower yield response than DAP (NFDC, 1986). In less intensive cropping systems areas, the move from low P analysis fertilizer (SSP) to high P-content fertilizer (DAP), and deep placement methods will contribute to improving P use efficiency (Bumb et al., 1996). In addition to technology-related improvement possibilities, policy measurement can help promote a more efficient P fertilizer use. These measures include allocating foreign exchange for improvement of P-fertilizers with adequate credit incentives to farmers (Cisse and Amar, 2000).

There have been many studies conducted on plant competition to determine the optimum plant density for maize (Olson and Sander, 1988). Yield reduction per plant was due to the effects of interplant competition for light, water, nutrition, and other potentially yield limiting environmental factors (Duncan, 2002). Increase in plant density delays maturity and decreases shelling percentage, thousand grain weight, grains ear^{-1} and grains row^{-1} (Sangoi et al., 2002; Ogunlela et al. 2005). Total dry matter, average leaf area and plant height maximized at 80,000 plants ha^{-1}, but harvest index decreased at high plant density (Amano and Salazer, 1989). Plant height and ear height increased with increasing plant density, but leaf area, ear length, grains row^{-1} and thousand grain weight decrease with increase in plant density, while number of leaves plant^{-1}, number of leaves above main ear and number of rows ear^{-1} are not affected by plant density (Hassan, 2000). Increasing plant density for short season maize increase cumulative intercepted photosynthetically active radiation, which compensate for a short growing season to achieve high yield (Edwards et al., 2005). Plant height and ear height increased but leaf area decreases with increase in plant density (Hassan, 2000). Maize height and maturity are highly correlated to leaf number (Cross and Zuber, 1973) and the relative growth rate of leaves decreases with leaf number (Milthorpe and Moorby, 1974). Plant density in maize affects plant architecture, alters growth and developmental patterns and influences carbohydrate production and partition (Casal et al., 1985).

The earlier published research work from the same study indicated that yield and yield components increased significantly when maize was planted at 80,000 plants ha^{-1} (D_3) and with application of P fertilizers than control (P not applied). In case of P-fertilizers, the highest benefit in terms of grain yield was obtained from DAP. Application of DAP at D_3 gave 15, 29 and 19% higher grain yield than its application at D_1 (40,000 plants ha^{-1}), D_2 (60,000 plants ha^{-1}) and D_4 (100,000 plants ha^{-1}), respectively (Amanullah et al., 2009).

The preceding limited literature suggests that P fertilizer and plant density affect growth and grain yield. However, research information is lacking on the interactive effects of plant density and source of P-fertilizer source on agronomic efficacy and profitability of maize in the various agro-ecological wheat-maize growing zones in this part of the world. For sustainable high crop production, improvement in the agronomic efficiency of P as well and net return of farmers, research on the interactive effects of plant density and P-fertilizer on maize are indispensable. This experiment was therefore performed with an objective to compare the economics and agronomic efficiencies of different P-fertilizers on maize maintained at different plant densities.

MATERIALS AND METHODS

Site Description

Field experiment was conducted at the Agriculture Research Farm of the Khyber Pakhtunkhwa Agricultural University, Peshawar during summer 2006 in order to find out the best P source and optimum planting density for profitable maize production. The experimental farm is located at 34.01° N latitude, 71.35° 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 the Kabul river. Soil texture is clay loam, low in organic matter (0.87%), extractable phosphorus (6.57 mg kg^{-1}), exchangeable potassium (121 mg kg^{-1}), and alkaline (pH 8.2) and is calcareous in nature. Soil physiochemical properties such as soil texture (Gee and Bauder, 1986), organic matter (Nelson and Sommers, 1982), ammonium bicarbonate (AB)-diethylenetriaminepentaacetic acid (DTPA) extractable phosphorus and exchangeable potassium (Soltanpour, 1985) were determined according to standard procedures. 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., 2010).

Experimentation

The experiment was laid out in a randomized complete block (RCB) design with split plot arrangement having four replications. Factorial experimental treatments used were P-fertilizers sources [S0, Control = P not applied; S_1, SSP = Single super phosphate, calcium dihydrogen phosphate (Ca $(H_2PO_4)_2$)+ calcium sulfate ($CaSO_4{\cdot}2H_2O$); S_2, NP = Nitrophos, calcium hydrogen phosphate (Ca HPO_4) + ammonium phosphate ($NH_4H_2PO_4$) + ammonium nitrate (NH_4NO_3); and S_3, DAP = Diammonium phosphate, $(NH_4)_2$ HPO_4] as main plots, while plant densities [D_1 = 40,000, D_2 = 60,000, D_3 = 80,000 and D_4 = 100,000 plants ha^{-1}] as sub-plots. There were 16 plots in each replication. The size of each sub plot was 4.2 × 4 m^2. Each sub-plot consisted of 6 rows, 4 m long with row to row distance of 70 cm. Phosphorus was applied at the rate of 60 kg P ha^{-1} using different P-fertilizers (S_1 S_2 and S_3) at the time of seedbed preparation and incorporated in the soil. Nitrogen in the form of urea was applied at the rate of 120 kg N ha^{-1} in three splits that were 33.3% at seedbed preparation, 33.3% at first irrigation and 33.3% at second irrigation. In case of SSP (18% P_2O_5), the whole N dose (120 kg ha^{-1}) was applied from urea (46% N), but in case of DAP (46% P_2O_5 and 18% N) and NP (23% P_2O_5 and 23% N), 96.5 and 60 kg N ha^{-1} was applied from urea, respectively. Maize variety Azam was sown at higher seed rate of 40 kg ha^{-1} and the desired plant densities were obtained by thinning at the early vegetative V3 stage (the leaves laid alternately and the stem apex is still below the soil surface).

Statistical Analysis

The data were statistically analyzed using analysis of variance (ANOVA) procedures according to the methods described by Steel and Torrie (1980), and the means between treatments were compared by least significant difference ($P \leq 0.05$).

Economic Analysis

Net return (the value of the increased yield produced as a result of P-fertilizers applied, less the cost of P-fertilizer) was determined according to the procedures described by Amanullah et al. (2010) and Bhatti (2006), while partial factor productivity (the ratio of the grain yield to the applied rate of P), agronomic efficiency (the ratio of the increase in grain yield over P-control plots to the applied rate of P) was determined according to Yadav (2003) as given in Table 1.

RESULTS AND DISCUSSION

Main Plots Effect (P-Fertilizers)

Application of different P-fertilizers resulted in greater PFP (partial factor productivity), AE (agronomic efficiency), GR (gross returns) and NR (net returns) as compared to P-control plots (Table 2), which probably may be due to the higher thousand grain weight, grains ear^{-1} and grain yield in the P applied plots than zero-P control plots (Amanullah et al., 2009)

TABLE 1 Abbreviations, formulae and units of different parameters studied in the experiment

Column	Parameter	Abbr.	Formula	Unit
1	Grain yield	GY	GY m^{-2} × 10,000	kg ha^{-1}
2	Partial factor productivity	PEP	GY ha^{-1} ÷ rate of P (60 kg ha^{-1})	kg grains kg^{-1} P
3	Increase in GY over control	GY_{IOC}	GY with P − GY without P	kg ha^{-1}
4	Agronomic efficiency	AE	GY_{IOC} ÷ rate of P (60 kg ha^{-1})	kg grains kg^{-1} P
5	Grain yield value	GY_V	GY ha^{-1} × value of grains kg^{-1}	Rs. ha^{-1}
6	Stover yield value	SY_V	SY ha^{-1} × value of stovers kg^{-1}	Rs. ha^{-1}
7	Gross return	GR	$GY_V + SY_V$	Rs. ha^{-1}
8	Increase in GR over control	GR_{IOC}	GR − P_c	kg ha^{-1}
9	P cost	P_c	*Price per bag ÷ P content in a bag	Rs. ha^{-1}
10	Net return	NR	GR_{IOC} − P_c	Rs. ha^{-1}

In case of compound fertilizers, i.e., DAP and NP (nitrophos) the value of N of these fertilizers is subtracted from their cost of P. The price of N kg^{-1} was determined from the current market price of urea (Rs. 28 kg^{-1} N).

which resulted in higher PFP, AE, GR and NR. Sahoo and Panda (2001) and Okalebo and Probert (1992) reported that P application to maize increased yield and yield components over the zero P-control. Among the fertilizers, DAP and SSP resulted in higher PFP (63.58 and 61.92 kg grains kg^{-1} P), AE (13.01 and 13.71 kg grains kg^{-1} P), GR (Rs. 102,187 and 99,460 ha^{-1}) and NR (Rs. 16,289 and 16,204 ha^{-1}), respectively than nitrophos (NP). Nitrophos stood at the bottom in the ranking of P-fertilizers with the lowest PFP (57.16 kg grains kg^{-1} P), AE (8.94 kg grains kg^{-1} P), GR (Rs. 91,418 ha^{-1}) and NR (Rs. 4472 ha^{-1}). The lower P prices using either SSP (Rs. 67 kg^{-1} P) and DAP (Rs. 111 kg^{-1} P) probably may be the possible cause of increase in both GR and NR over NP with higher P price (Rs. 128.5 kg^{-1} P). Earlier, Reghurum et al. (1994) also reported that DAP is the better P-fertilizer source than other P-fertilizers. However, Osinama (1995) reported no significant differences

TABLE 2 Effect of P-fertilizers on profitability of maize in Northwest Pakistan

Phosphorus source	GY	PFP	GY_{ioc}	AE	GY_{vPKR}	SY_{vPKR}	GR_{PKR}	GR_{iocPKR}	P_c	NR
Control	2893	—	—	—	69431	9805	79236	—	0	—
DAP	3815	63.58	781	13.01	91550	10637	102187	22951	6662	16289
SSP	3715	61.92	822	13.71	89166	10294	99460	20224	4020	16204
NP	3429	57.16	537	8.94	82304	9114	91418	12182	7710	4472
$LSD_{0.05}$	592	ns	ns	ns	14204	ns	14101	ns	—	8570

NS: Not significant.

in grain yield, stover yield and harvest index of maize while using different P fertilizers. The differential response between our results and the results drawn by Osinama et al. (1995) probably may be due to the difference in the soil fertility status, variation in the genetic makeup of verities used, and the response of varieties to different sources of P application under different environments.

Sub-Plots Effect (Planting Density)

All the economic parameters in this study showed a positive relationship with increase in plant density up to D_3 (80,000 plant ha^{-1}), and beyond this density all of them decreased dramatically when maize crop was maintained at the highest density of D_4 (100,000 plant ha^{-1}) (Table 3). Among plant densities, D_3 stood first with maximum PFP (69.60 kg grains kg^{-1} P) ($D_3 > D_4 > D_1 > D_2$), AE (18.21 kg grains kg^{-1} P) ($D_3 > D_2 > D_4 > D_1$), GR (Rs. 105,698 ha^{-1}) ($D_3 > D_1 > D_2 > D_4$), and NR (Rs. 21,461 ha^{-1}) as compared to other plant densities ($D_3 > D_1 > D_2 > D_4$). The possible reason could probably may be that at D_3 most plants were healthy, vigorous and absorbed the nutrients especially P more efficiently, but when plant density was increased to D_4 then because of interplant competition a problem of lodging occurred that not only lowered maize crop growth rate, leaf area, leaf area index (unpublished data), but also declined stover and grain yields as well as harvest index of maize that resulted in lower PFP, AE, GR and NR at D_4 than D_3 (Amanullah et al., 2009). Our results are comparable to those of Ogunlela (2005) and Duncan (2002) who noted decline in maize yields while increasing plant densities to the highest level. On the other hand, the intra-plant competition at lower densities (D_1 and D_2) of maize reduced maize leaf area and leaf area index, crop growth rate, and dry matter accumulation (unpublished data) as well as grain yield and yield components per unit land area declined significantly as compared to D_3 (Amanullah et al., 2009) which was responsible for lower PFP, AE, GR and NR at D_1 and D_2 than D_3 Our results are in agreement with those of Amano and Salazer (1989) who reported higher leaf area, stover yield and harvest index of maize at 80,000 plants ha^{-1} than at other plant densities. Andrade et al. (2002) reported that the increase in the yields at the intermediate densities of maize might

TABLE 3 Effect of plant densities on profitability of maize in Northwest Pakistan

Plant density ha^{-1}	GY	PFP	GY_{ioc}	AE	GY_v	SY_v	GR	GR_{ioc}	P-cost	NR
40,000	3145	55.19	479	7.98	75471	7868	83339	16422	4598	10292
60,000	3117	54.71	661	11.02	74813	9109	83921	16229	4598	10099
80,000	3903	69.60	1093	18.21	93668	12031	105698	27592	4598	21461
100,000	3687	64.04	620	10.34	88499	10844	99342	13567	4598	7436
$LSD_{0.05}$	351	5.6	250	4.16	8428	1228	8853	6733	—	6507

be due to the improvement in light interception during the critical period for grain set.

CONCLUSIONS

The recent higher P-fertilizers prices and the lower income of the growers had negative impacts on the maize profitability in northwest Pakistan. The results of this study indicated that maize profitability changes while using different sources of P-fertilizers and variation in plant density. Growing maize at 80,000 plants ha^{-1} applied with P-fertilizers in the form of either DAP or SSP had the maximum positive impact on maize profitability than NP (nitrophos) and control (P not applied) in the study area. The recommended phosphorus source for increasing maize profitability may vary among the diverse agro-ecological zones because of fluctuation in the prices of P-fertilizers in different parts of Khyber Pakhtunkhwa, differences in climatic conditions and soil characteristics. This problem poses a challenge for the development of technical recommendations targeted for diverse environments of Khyber Pakhtunkhwa.

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