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IMPACT OF PLANTING DENSITY AND P-FERTILIZER SOURCE ON THE GROWTH ANALYSIS OF MAIZE

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Abstract

Phosphorus (P) is one the most important factor affecting maize (*Zea mays* L.) growth and yield in the wheat-maize cropping system. To investigate the impact of P sources (control, DAP = Diammonium phosphate, SSP = single super phosphate, and NP = nitrophos) and planting densities (D_1 = 4, D_2 = 6, D_3 = 8, and D_4 = 10 plants m^{-2}) on maize growth analysis (cv. Azam), field experiment was conducted at the New Developmental Agricultural Research Farm of NWFP Agricultural University, Peshawar, during summer 2006. Among all the parameters studied, P source had significant effects on CGR (crop growth rate), LAI (leaf area index), PER (plant elongation rate), LER (leaf expansion rate), DM (dry matter) and grain yield, but had no significant effects on AGR (absolute growth rate), NAR (net assimilation rate), RGR (relative growth rate) and LAR (leaf area ratio). Plots applied with DAP or SSP had maximum AGR, CGR, RGR, LAI, LER, DM and grain yields as compared to plots applied with NP and with zero-P control plots. Increase in planting density had negative effects on AGR, NAR, RGR and grain yield plant^{-1} (D1 > D2 > D3 > D4) and had positive effects on LAI, LAR, LER and PER ($D_1 < D_2 < D_3 < D_4$). Growing maize at D_3 (8 plants m^{-2}) had highest CGR, DM and grain yields m^{-2} ($D_3 > D_4 > D_2 > D_1$). The findings suggest that growing maize at D_3 applied with SSP or DAP could be more beneficial in the wheat-maize cropping system in the study area.

Introduction

Maize (*Zea mays* L.) is the second most important crop after wheat in the North West Frontier Province of Pakistan but its yield per unit area is very low (Amanullah *et al*., 2009). The soils of NWFP have low organic matter content and low to medium available P. These soils contain high $CaCO_3$ 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 P fertilizer (Hussain & 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).

Judicious use of P-fertilizer is a key factor in the cereals based system of NWFP for sustainable agriculture. Imbalanced fertilizer use, especially in terms of phosphate (P) compared with N, has created concern in NWFP as it may affect overall agricultural productivity and economic growth. 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 & Amar, 2000).

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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 & Probert, 1992; Sahoo & Panda, 2001). Reduction in number of adventitious roots on P-deficient maize plants has negative effects 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 of the delayed appearance of leaves on P-deficient plants and reduction of their final surface area (Plenet *et al*., 2000a). Plenet *et al*., (2000b) found that the lower biomass accumulation in the P deficient plants is mainly due to P deficiency on leaf growth and its subsequent effect on PAR absorption. 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 SSP (single super phosphate), TSP (triple super phosphate), 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 (Raghurum *et al*., 2000), 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 (Anon., 1986).

There have been many studies conducted on plant competition to determine the optimum plant density for maize (Olson & Sander, 2003). 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 delay 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 & Salazer, 1989). Plant height and ear height increases with increase plant density, but leaf area, ear length, grains row^{-1} and thousand grain weight decreases 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). Toler *et al*., (1999) reported 15% higher light interception and grain yield at higher than at lower plant density of maize. Increasing plant density for short season maize increase cumulative intercepted photo synthetically active radiation, which compensate for a short growing season to achieve high yield (Edwards *et al*., 2005). Plant height and ear height increases but leaf area decreases with increase in plant density (Hassan, 2000). Maize height and maturity are highly correlated to leaf number (Cross & Zuber, 1973) and the relative growth rate of leaves decreases with leaf number (Milthorpe & Moorby, 1974). Plant density in maize affects plant architecture, alters growth and developmental patterns and influences carbohydrate production and partition (Casal, 1985).

The preceding limited literature suggests that P fertilizer and plant density affect both growth analysis and grain yield. However, research information is lacking on the interactive effects of plant density and source of P fertilizer on maize in the various agro-ecological wheat-maize growing zones in this part of the world. For sustainable higher crop productivity and net returns research on the interactive effect of plant density by P-fertilizer are indispensable in the cereal based system. This experiment was therefore performed with an objective to investigate the impacts of different P fertilizer sources on the growth and yield of maize maintained at different planting densities.

Materials and Methods

Site description: Field experiments were conducted at the Agriculture Research Farm of the NWFP Agricultural University, Peshawar during summer 2006 in order establish a proper phosphorus management system for maize crop. 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 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. Mean annual rainfall in the region varies from 300 to 500 mm $year^{-1}$ of which 70 % rainfall occurs in summer (Amanullah et al. (2009b).

Experimentation: The experiment was laid out in a randomized complete block (RCB) design with split plot arrangement having four replications. Factorial experimental treatments were P-fertilizers sources [S_0 (Control = P not applied), S_1 (SSP = Single super phosphate, Ca $(H_2PO_4)_2 + CaSO_4.2H_2O$), S_2 (NP =Nitrophos, Ca $HPO_4 + NH_4H_2PO_4 + NH_4NO_3$) and S_3 (DAP = Diammonium phosphate, $(NH_4)_2\ HPO_4$)] were allotted to main plots while plant densities [D_1 = 4, D_2 = 6, D_3 = 8 and D_4 = 10 plants m^{-2}] were allotted to 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 at the rate of 60 kg P ha^{-1} was applied using different P-fertilizers (S_0, S_1 S_2 and S_3) during seed bed preparation and incorporated in the soil. Nitrogen was applied at the rate of 120 kg N ha^{-1} in three splits that is 33.3% at seedbed preparation, 33.3% at first irrigation and 33.3% at second irrigation. In case of SSP (18 % P_2O_5) 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 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). Data were recorded on growth analysis i.e., AGR (absolute growth rate), CGR (crop growth rate), NAR (net assimilation rate), RGR (relative growth rate), LAR (leaf area ratio), LAI (leaf area index), LER (Leaf expansion rate), PER (plant elongation rate) according to Gardner *et al*., (1985) and Amanullah *et al*., (2008).

Statistical analysis: Data were subjected to analysis of variance (ANOVA) according to the methods described by Steel *et al*., (1996), and means between treatments were compared by least significant difference (LSD) at $p \leq 0.05$. A brief summery of ANOVA is given in Table 1.

Results

Growth analysis: Phosphorus source (P) had significant impacts on CGR, LAI, LER, PER, DM and grain yields but had no significant effects on AGR, NAR, RGR, and LAR of maize at $p \leq 0.05$ (Table 2). Plots applied with DAP or SSP gave maximum AGR (1.56 g $plant^{-1}$ day^{-1}), CGR (10.08 g m^{-2} day^{-1}), RGR (97.11 g m^{-2} day^{-1}), LAI (2.95), LER (2.85 cm^{-2} day^{-1}), DM (1042 g m^{-2}) and grain yield (60.83 g $plant^{-1}$ and 381 g m^{-2}) as compared to plots applied with NP and with zero P-control (DAP and SSP > NP and zero P-control). Although, P source had no significant effects on LAR, yet it reached to a maximum level (36.2 cm^{-2} g^{-1}) in plots applied with NP. Plots applied with any of P fertilizers had significantly higher PER (1.79 to 1.82 cm day^{-1}) than zero-P control (1.63 cm day^{-1}).

Table 1. Summary of analysis of variance (ANOVA) for various parameters studied in the experiment.

S. No.	Parameters Studied	Unit	P source (S) Main plots	Plant density (D) Sub plots	S x D Interactions
1.	AGR	g plant^{-1} day^{-1}	ns	*	ns
2.	CGR	g m^{-2} day^{-1}	*	**	ns
3.	NAR	g m^{-2} day^{-1}	ns	**	ns
4.	RGR	g m^{-2} day^{-1}	ns	**	*
5.	LAI	--	**	**	ns
6.	LAR	cm^{-2} g^{-1}	ns	**	ns
7.	LER	cm^{2} day^{-1} m^{-2}	*	**	ns
8.	PER	cm day^{-1}	*	**	*
9.	DM yield	g m^{-2}	*	**	ns
10.	Grain yield	g m^{-2}	*	**	ns
11.	Grain yield	g plant^{-1}	*	**	*

* = Stands for significant at $p \leq 0.05$
** = Stands for significant at $p \leq 0.01$
Ns = Stands for non significant

Increase in planting density from D_1 (lowest) to D_4 (highest) had significantly negative effects ($D_1 > D_2 > D_3 > D_4$) on AGR (1.99 to 0.99 g plant^{-1} day^{-1}), NAR (4.70 to 2.64 g m^{-2} day^{-1}), RGR (98.51 to 93.92 g m^{-2} day^{-1}) and grain yield plant^{-1} (78.62 to 36.87 g plant^{-1}). In contrast, increase in planting density had positive effects ($D_1 < D_2 < D_3 < D_4$) on LAI (1.62 to 3.76), LAR (21.5 to 36.2 cm^{-2} g^{-1}), LER (160.11 to 353.49 cm^{-2} day^{-1} m^{-2}) and PER (1.69 to 1.81 cm day^{-1}) (Table 2). Increasing planting density from D_1 to D_3 increased CGR (7.54 to 10.70 g m^{-2} day^{-1}), DM accumulation (765 to 1112 g m^{-2}) and grain yield (312 to 390 g m^{-2}) to the highest level but further increase in planting density to the highest level (D_4), declined CGR (9.87 g m^{-2}), DM (1051 g m^{-2}) and grain yield (369 g m^{-2}).

Interaction between P sources (S) by planting density (D) had significant effects on RGR, PER and grain yield plant^{-1} (Table 2). Increase in planting density had negative effects on the RGR of maize in plots applied with P fertilizers ($D_1 > D_2 > D_3 > D_4$). On the other hand, plots with zero-P control, RGR increased while increasing plant density from D_1 to D_2 but beyond $D_{2,}$ RGR decreased significantly while increasing density from D_2 to D_4 ($D_1 < D_2 > D_3 > D_4$). When arranged across planting density, among P fertilizers, SSP ranked first at D_1 (SSP > DAP > NP > control), NP at D_4 (NP > control > SSP > DAP), and DAP at D_3 (DAP > control > SSP > NP), while at $D_{2,}$ maximum RGR was calculated when P was not applied (control > SSP > DAP > NP).

When arranged against planting density, PER increased with P application than zero-P control. Among P fertilizers, SSP ranked first at D_1 (SSP > DAP > NP > control), NP at D_2 and D_4 (NP > SSP > DAP > control), and DAP at D_3 (DAP > NP > SSP > control). When arranged against P source, PER increased with increase in plant density in plots applied with NP and the zero-P control plots ($D_1 < D_2 < D_3 < D_4$). On the other hand, plots applied with DAP, had higher PER while increasing plant density from D_1 to $D_{3,}$ but further increase to D_4 declined PER ($D_1 < D_2 < D_3 > D_4$). Contrary to it, plots applied with SSP, had higher PER at D_1 than D_2' but beyond D_2' plant density had positive effects on PER ($D_1 > D_2 < D_3 < D_4$).

Table 2. Effects P-fertilizer source and planting density on AGR, CGR, NAR, RGR, LAI, LAR, LER, PER, DM and grain yield of maize.

Parameters	AGR g $plant^{-1}$ day^{-1}	CGR g m^{-2} day^{-1}	NAR g m^{-2} day^{-1}	RGR g m^{-2} day^{-1}	LAI	LAR cm^{-2} g^{-1}	LER cm^{-2} m^{-2} day^{-1}	PER cm day^{-1}	DM g m^{-2}	GY g m^{-2}	GY g $plant^{-1}$
Main plots (P source)											
S_0 = Control	1.33	8.66	3.72	96.32	2.53	27.6	242.90	1.63	900	289	1.12
S_1 = DAP	1.56	10.08	3.73	96.87	2.93	27.8	282.38	1.79	1040	381	1.54
S_2 = SSP	1.42	9.34	3.31	97.11	2.95	30.3	285.02	1.81	967	372	1.39
S_3 = NP	1.30	8.43	3.28	96.36	2.74	31.3	263.09	1.82	876	343	1.31
LSD for P source ($p \leq 0.05$)	**ns**	**1.09**	**ns**	**ns**	**0.26**	**Ns**	**27.43**	**0.12**	**110**	**59.2**	**0.25**
CV %	**16.1**	**14.9**	**17.7**	**1.8**	**11.7**	**17.2**	**12.8**	**8.5**	**14.5**	**21.4**	**23.8**
Sub plots (plants m^{-2})											
D_1 = 4	1.89	7.54	4.70	98.51	1.62	21.5	160.11	1.69	765	314	1.93
D_2 = 6	1.40	8.41	3.45	98.06	2.44	29.1	239.53	1.73	857	312	1.32
D_3 = 8	1.34	10.70	3.24	96.18	3.33	30.2	320.26	1.80	1112	390	1.23
D_4 = 10	0.99	9.87	2.64	93.92	3.76	36.2	353.49	1.81	1051	369	0.88
LSD for plant density ($p \leq 0.05$)	**0.18**	**0.77**	**0.35**	**0.44**	**0.19**	**2.86**	**18.72**	**0.04**	**80**	**35.1**	**0.13**
Interactions (S x D)											
S_0 x D_1	1.78	7.13	5.07	96.42	1.41	19.1	135.71	1.57	740	264	1.55
S_0 x D_2	1.32	7.89	3.69	99.02	2.14	26.9	212.38	1.63	797	262	1.16
S_0 x D_3	1.27	10.15	3.46	95.94	2.93	27.9	281.20	1.64	1059	308	0.97
S_0 x D_4	0.94	9.45	2.64	93.91	3.65	36.7	342.32	1.67	1005	322	0.80
S_1 x D_1	2.10	8.40	5.19	98.56	1.64	19.5	161.07	1.71	851	384	2.38
S_1 x D_2	1.58	9.48	3.62	97.83	2.63	27.6	257.72	1.73	969	328	1.41
S_1 x D_3	1.49	11.92	3.47	97.82	3.46	28.4	338.31	1.88	1219	450	1.50
S_1 x D_4	1.05	10.53	2.65	93.27	3.99	35.7	372.40	1.83	1130	364	0.85
S_2 x D_1	1.86	7.44	4.13	100.77	1.80	24.7	181.72	1.82	739	317	2.03
S_2 x D_2	1.44	8.65	3.36	98.29	2.57	29.8	253.07	1.74	879	322	1.28
S_2 x D_3	1.34	10.73	2.85	95.70	3.79	34.2	362.79	1.82	1122	444	1.32
S_2 x D_4	1.06	10.56	2.90	93.69	3.66	32.5	342.50	1.86	1128	403	0.92
S_3 x D_1	1.80	7.19	4.42	98.29	1.65	22.8	161.95	1.68	731	293	1.76
S_3 x D_2	1.27	7.61	3.13	97.10	2.42	32.0	234.90	1.83	782	335	1.43
S_3 x D_3	1.25	9.99	3.18	95.25	3.14	30.2	298.75	1.86	1050	358	1.11
S_3 x D_4	0.89	8.93	2.38	94.82	3.76	40.0	356.73	1.89	941	386	0.96
LSD for S x D ($p \leq 0.05$)	**ns**	**ns**	**ns**	**0.36**	**ns**	**ns**	**ns**	**0.03**	**ns**	**ns**	**0.12**
CV %	**12.7**	**11.7**	**14.2**	**1.6**	**9.6**	**13.7**	**9.7**	**3.5**	**11.8**	**14.2**	**13.6**

AGR = absolute growth rate, CGR = crop growth rate, NAR = net assimilation rate, RGR = relatively growth rate, LAI = leaf area index, LAR = leaf area ratio, LER = leaf expansion rate, PER = plant elongation rate, DM = dry matter, GY = grain yield, DAP = Diammonium phosphate, SSP = single super phosphate and NP = nitrophos

Plots applied with NP and with zero-P control gave higher grain yield plant^{-1} while decreasing planting density ($D_1 > D_2 > D_3 > D_4$). On the other hand, plots received DAP or SSP, produced maximum grain yield plant^{-1} at D_1 and D_3 ($D_1 > D_3 > D_2 > D_4$). When arranged across planting density, all P sources produced higher grain yield than zero-P control. Among P sources, DAP ranked first at D_1 and D_3 (DAP > SSP > NP > control), NP at D_2 (NP > DAP > SSP > control), and SSP was better at D_4 (SSP > NP > DAP > control).

Discussions

Phosphorus application significantly increased CGR, LAI, LER, PER, DM and grain yields of maize than zero-P control plots (Table 2). The decline in CGR, DM accumulation and grain yield in the zero-P control plots may be due to the decrease in LAI, LER and PER of maize in the zero-P control plots as compared to the higher LAI, LER and PER in the plots which received P. These results are in confirmation with the results obtained by Pellerin *et al*., (2000) who reported that P deficiency in the control plots had negative effect on LAI and its subsequent effect on PAR absorption, C nutrition and maize yields. But reduction in LAI and LER in the zero-P control plots may be due to the reduction in the leaf area of maize as compared to higher leaf area in the plots that received P. Plenet *et al*., (2000a) reported that reduction in LAI of maize is the consequence of reduction in the leaf area. Plenet *et al*., (2000b) found that the lower biomass accumulation in the control treatment is mainly due to the effect of P deficiency on leaf growth and its subsequent effect on PAR absorption. Increase in leaf area, plant heights DM accumulation and grain yield in the P applied plots over zero-P control plots is also reported by Sahoo & Panda (2001) and Okalebo & Probert (1992).

Plots applied with either DAP or SSP were better in terms of AGR, CGR, LAI, LER, DM and grain yield than NP and zero-P control plots (Table 2). Raghurum *et al*., (2000) reported that DAP is better P fertilizer than other sources of P for maize crop. The increase in grains ear^{-1}, grains weight, plant height and leaf area (Amanullah *et al*., 2009c) in the plots applied with DAP or SSP may be the possible cause of higher DM accumulation and grain yield in maize. Increase in the CGR, LAI and LER of maize may be due to the increase in the leaf area of maize with application of SSP or DAP as compared to smaller leaf area of maize with application of NP (nitrophos) and in the zero-P control plots. Increase in maize leaf area with application of DAP was earlier reported by Singh (1984). Plots applied with P fertilizers had significantly higher PER (plant elongation rate) than the zero-P control plots. The possible reason for increase in the rate of maize heights in the plots applied with P fertilizers over control may be due to the increase in the uptake efficiency of crop nutrients particularly N that increased maize heights more in the plots applied with P fertilizers than in the zero-P control plots. These findings are in agreement with those of Okalebo & Probert (1992) and Sahoo & Panda (2001) who reported significant increase in maize heights with P application over control.

Increase in planting density had negative effects on AGR, NAR and RGR, and had positive effects on LAI, LAR, LER and PER (Table 2). The decrease in AGR, NAR, and RGR while increasing planting density may be due the decrease in light interception and LAI at low than at high plant density. In contrast, the increase in LAI, LAR, LER and PER with increase in plant density may be due to the increase in light interception at high than at low plant density (Amanullah *et al*., 2008). The increase in the PER at higher densities may be due to strong competition among the plants for light that is the possible cause for increase in maize heights. Our results are in conformity with those of Ogunlela *et al*., (2005) who reported taller maize plants at high than at low density.

CGR, DM and grain yield reached to a maximum level when maize was planted at D_3 (Table 2). The possible reason of significant increase in CGR, DM and grain yield at D_3 could be that at this density most plants were healthy and vigorous which may helped the plants to absorb water, nutrients and light more efficiently that may have resulted in the higher CGR, DM and grain yields. The increase in the yields of maize at D_3 may be due to the improvement in light interception during the critical period for grain set (Andrade *et al*., 2002). The intraplant competition at lowest densities (D_1 and D_2) and interplant competition at highest density (D_4) reduced leaf area, weight plant^{-1}, grains weight and number ear^{-1} (Amanullah *et al*., 2009c) and so CGR (g plant^{-1} day^{-1}), DM (g plant^{-1}) and grain yield (g m^{-2}) declined at D_1, D_2 and D_4 as compared to higher CGR, DM and grain yield at D_3.

The decrease in CGR, DM and grain yield at lower densities (D_1 and D_2) may be due the decrease in light interception at low than at high plant density. In contrast the decrease in CGR, DM and grain yield at the highest plant density (D_4) may be due to shortage of water and nutrients availability in the dense plants that negatively affected assimilates formation and hormonal mechanism of plants at the highest plant density (D_4). These results are in line with those of Ogunlela, 2005), Duncan (2002) and Hassan (2000) who observed decline in maize yield while increasing plant density.

Conclusions

Growing maize at 80,000 plants ha^{-1} and application of P-fertilizer had the maximum positive impact on maize crop growth rate, dry matter accumulation and grain yield in the wheat-maize cropping system. At this plant density, DAP had the highest crop growth rate, dry matter and grain yield, while NP had the poorest performance. Overall, DAP was the most effective P fertilizer, followed by SSP, and NP ranked in the bottom. Further research on the use of different sources of P fertilizer management practices need to be developed for different cropping systems in various agro-climatic zones of NWFP.

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