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Phosphorus and Sulfur Application Improves the Chickpea Productivity under Rainfed Conditions

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ABSTRACT

Field experiments were conducted at two locations in northern rainfed Punjab, Pakistan to assess the seed yield of chickpea (*Cicer arietinum* L.) in response to application of different levels of sulfur and phosphorus. The treatments comprised three levels (0, 40 & 80 kg P_2O_5 ha^{-1}) of phosphorus and three levels (0, 15 & 30 kg S ha^{-1}) of sulfur from two sulfur sources (gypsum & ammonium sulfate) in different combinations. Phosphorus was applied in the form of triple super phosphate. Crop was harvested at maturity and data were recorded for seed yield. Application of phosphorus and sulfur resulted in significant increase in seed yield up to 34 and 17 % over control, respectively. Effect of combined application of phosphorus and sulfur was synergistic at nutrient application rate of 40 kg phosphorus and 15 kg sulfur ha^{-1}, while antagonistic at 80 kg phosphorus and 30 kg sulfur ha^{-1}. Value cost ratio was higher for combined application of phosphorus and sulfur as compared to their sole application. Therefore either 80 kg phosphorus along with 15 kg sulfur ha^{-1} or 40 kg phosphorus in combination with 30 kg sulfur ha^{-1} should be applied in order to maximize profit from chickpea crop under rainfed conditions.

Key Words: *Cicer arietinum*; Agronomic efficiency; Synergism; Antagonism; VCR

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is an important pulse crop of rainfed areas in semiarid/arid climate. Average chickpea yield in Pakistan is 0.7 Mg ha^{-1} (Government of Pakistan, 2010), which is very low as compared to developed countries of the world such as China (2.4 Mg ha^{-1}), Canada (1.9 Mg ha^{-1}) and USA (1.7 Mg ha^{-1}) (FAO, 2009). This low yield may be attributed mainly to erratic rainfall, low plant population and imbalanced fertilizer use.

Use of phosphorus (P) for chickpea is very limited, whereas sulfur (S) application is not practiced by the farmers. Phosphorus application significantly affects many aspects of plant physiology including photosynthesis, flowering, fruiting and maturation which ultimately results in better chickpea yield (Brady & Weil, 2005). It is also essential component of nucleic acids, phosphatides, phospholipids, chromosomes, coenzymes, nicotinamide adenine dinucleotide and adenosine tri phosphate (Ahmad & Rashid, 2003). Similarly S has important role in formation of chlorophyll, reduction of CO_2 and production of organic compounds (Scherer, 2008).

There exists a synergistic relationship between P and S at low level of S application and antagonistic relationship at higher level of S application in wheat (Randhawa & Arora, 2000) and chickpea (Islam *et al.*, 2009). Likewise, Pandey *et al.* (2003) also observed synergistic relationship between the two nutrients in linseed. Both positive and negative interactions between P and S have been reported depending upon rate of nutrient application, initial fertility status of soil, test crop, climatic condition and crop management practices etc. (Tiwari & Gupta, 2006).

In Pakistan, research work regarding interaction of P and S and their role in legume's growth is very rare. Therefore, present study was conducted to assess the interactive effect of sulfur and phosphorus application on seed yield of chickpea under rainfed conditions of northern Punjab, Pakistan.

MATERIALS AND METHODS

Field experiments were conducted using chickpea cultivar Balkassar 2000 at Barani Agricultural Research Institute (BARI), Chakwal and farmer's field Talagang during 2006-2007 and 2007-2008. Physical and chemical properties of the experimental sites are shown in Table I. The

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Table I: Location, rainfall and physical and chemical properties of soils of experimental sites

Parameter	Unit	Chakwal	Talagang
Latitude	N	32.5°	32.5°
Longitude	E	72.4°	72.2°
Mean annual rainfall (1979-2009)	mm	630	450
Cropping season (October to March)			
rainfall during (i) 2006-07	mm	385	362
(ii) 2007-08		90	30
Sand	%	69	80.8
Silt	%	21	6.7
Clay	%	10	12.5
Texture	-	Sandy loam	Loamy sand
pH	-	7.6	7.7
ECe	dSm^{-1}	0.32	0.26
Total organic carbon	$mg\ g^{-1}$	3.7	1.8
$CaCO_3$	%	5.2	2.9
Total N	%	0.02	0.01
NO_3-N (AB-DTPA extractable)	$\mu g\ g^{-1}$	11.2	5.6
Phosphorus (AB-DTPA extractable)	$\mu g\ g^{-1}$	3	1.4
Sulphate- sulphur ($CaCl_2$ extractable)	$\mu g\ g^{-1}$	6.4	7.5
Zinc (AB-DTPA extractable)	$\mu g\ g^{-1}$	0.75	1.3
Copper (AB-DTPA extractable)	$\mu g\ g^{-1}$	1.21	0.92
Iron (AB-DTPA extractable)	$\mu g\ g^{-1}$	7.82	5.63
Manganese (AB-DTPA extractable)	$\mu g\ g^{-1}$	2.98	2.1

Table II: Effect of year and location on seed yield of chickpea (Mg ha^{-1})

Year	Chakwal	Talagang	Mean
2006-07(Y_1)	1.19 b	1.95 a	1.57 a
2007-08 (Y_2)	0.79 d	1.05 c	0.92 b
Mean	0.99 b	1.50 a	1.25

LSD value for year × location interaction =0.07

trial was laid out in randomized complete block design with split split plot arrangement (plot size of 1.5 ×3.5 m at BARI Chakwal & 1.8 × 4 m at farmer's field Talagang) keeping P in main plots, S sources in sub plots and S levels in sub-sub plots. There were eighteen treatments having different combinations of P (0, 40, 80 kg ha^{-1}) and S rates (0, 15, 30 kg ha^{-1}) from two S sources (gypsum and ammonium sulfate). Starter dose (26 kg ha^{-1}) of nitrogen (N) was applied in the form of urea. However in S treatments, urea dose was adjusted accordingly after taking into consideration the addition of N from ammonium sulfate (AS). Phosphorus was applied in the form of triple super phosphate. All the treatments were replicated three times. Chickpea crop was sown maintaining row to row distance of 30 cm. All the fertilizers were applied as basal dose. Crop was grown under rainfed conditions and no supplemental irrigation was applied. Total rainfall during cropping season (October to March) was 385 and 362 mm during first year and 90 and 30 mm during second year of experiment at Chakwal and Talagang, respectively. At maturity, crop from an area of one meter square in the middle of each plot was harvested separately. The plant samples were dried and data was recorded for seed yield. Data on all observations were subjected to analysis of variance (ANOVA) by using software MSTATC. Treatment means were compared by least significant difference (LSD) test. Further statistical analysis was also done to compare different treatment combinations using orthogonal contrasts and their co-efficients (Peterson, 1977).

Nutrient interactions (synergistic or antagonistic) were calculated by comparing the yield increase (in terms of kg ha^{-1} over control) due to combined P and S application with that of individual/separate applications (Fageria, 2001). Agronomic efficiency of applied nutrients was calculated as follows (Cassman *et al.,* 1998).

Agronomic efficiency = kg increase in seed yield per kg of applied nutrient = $(Y_f - Y_0)/F$

Where Y_f and Y_0 stand for seed yield in fertilized and in control plot, respectively, whereas F is amount of nutrient applied in kg. Value cost ratio (VCR) was calculated with the help of following formula (FAO, 2000).

VCR = Value of increased yield / Cost of fertilizer

RESULTS

There was significant difference between years and locations in respect of seed yield (Table II). The highest seed yield was recorded at Talagang during first year, which was followed by Chakwal during same year. Seed yield was 51% higher at Talagang as compared to Chakwal. Similarly, it was 41% higher during first year as compared to second year.

Phosphorus application resulted in significant increase in seed yield at both the locations (Table III). Higher and lower level of P differed significantly in respect of seed yield. There was an increase up to 22 and 34% with the application of 40 and 80 kg P_2O_5 ha^{-1}, respectively. Data pooled over years showed that seed yield increased from 0.84 to1.08 Mg ha^{-1}at Chakwal and from 1.26 to 1.72 Mg ha^{-1} at Talagang as P application rate was enhanced from 0 to 80 kg P_2O_5 ha^{-1}.

There was significant difference between two S sources regarding seed yield with comparatively higher seed yield recorded with AS application (Table III). On an average, seed yield was higher by 5% in AS treated plots as compared to gypsum. Main effect of S was also significant on seed yield with the highest yield recorded with the application of 30 kg S ha^{-1} (Table III). There was an increase of 9 and 13% with application of 15 and 30 kg S ha^{-1}, respectively. Seed yield increased from 0.93 to 1.04 Mg ha^{-1} at Chakwal and from 1.39 to 1.59 Mg ha^{-1} at Talagang as S application rate was enhanced from 0 to 30 kg S ha^{-1}.

Interaction between P and S sources was not significant (Table III). However, interaction between P and S levels was significant. Orthogonal comparison of P_0 vs. P_{40} and P_{80} for data pooled over years for Chakwal indicated significant increase in seed yield due to P application at all S levels; however contrast between P_{40} and P_{80} showed non-significant difference at S_{30} (Table IV). A similar trend was also observed for Talagang during first crop growing season (2006-2007) and for data pooled across locations and years.

Table III: Seed yield (Mg ha^{-1}) as function of P and S levels and S sources

Effect	Chakwal 2006-2007	Chakwal 2007-2008	Mean	Talagang 2006-2007	Talagang 2007-2008	Mean	Overall Mean
P levels (kg P_2O_5 ha^{-1})							
0	0.98 c	0.70 c	0.84 c	1.64 b	0.88 c	1.26 c	1.05 c
40	1.28 b	0.81 b	1.05 b	1.98 ab	1.05 b	1.51 b	1.28 b
80	1.32 a	0.85 a	1.08 a	2.22 a	1.21 a	1.72 a	1.41 a
LSD value	0.02**	0.03**	0.01**	0.4**	0.02**	0.07**	0.07**
S sources							
Gypsum	1.18	0.78	0.98 b	1.86 b	1.03 b	1.44 b	1.21 b
Ammonium sulfate	1.20	0.80	1.00 a	2.03 a	1.06 a	1.55 a	1.27 a
LSD value	NS	NS	**	*	**	**	**
S levels (kg S ha^{-1})							
0	1.11 c	0.74 c	0.93 c	1.81 b	0.97 c	1.39 c	1.15 c
15	1.22 b	0.80 b	1.00 b	1.98 a	1.04 b	1.51 b	1.26 b
30	1.25 a	0.83 a	1.04 a	2.05 a	1.12 a	1.59 a	1.31 a
LSD value	0.02**	0.02**	0.01**	0.1**	0.02**	0.07**	0.02**
LSD vales for Interaction effects							
P × S sources	NS	NS	NS	NS	NS	NS	NS
P × S levels	0.03**	NS	0.02**	0.16*	0.03**	NS	0.04*
S sources × S levels	0.03*	NS	0.02*	NS	0.03*	NS	0.03*
P × S sources × S levels	NS	NS	NS	NS	NS	NS	NS

Means with different letters differ significantly according to Least Significant Difference (LSD) test (*P<0.05*). NS stands for non-significant difference, * and ** denote significance at $P < 0.05$ and $P < 0.01$ levels, respectively

Table IV: Probability (*P*) values and means for two orthogonal contrasts constructed for three levels of P with in each S level

Locations	Years	Effect	*P values* S_0	*P values* S_{15}	*P values* S_{30}	Effect	Means S_0	Means S_{15}	Means S_{30}
Chakwal	2006-2007	P_0 vs. P_{40} and P_{80}	< 0.001	< 0.001	< 0.001	P0	0.93	0.98	1.02
		P_{40} vs. P_{80}	0.003	< 0.001	NS	P1	1.17	1.30	1.37
						P2	1.22	1.38	1.37
Chakwal	Pooled across years	P_0 vs. P_{40} and P_{80}	< 0.001	< 0.001	< 0.001	P0	0.79	0.85	0.88
		P_{40} vs. P_{80}	< 0.001	< 0.001	0.26	P1	0.96	1.06	1.11
						P2	1.02	1.11	1.12
Talagang	2006-2007	P_0 vs. P_{40} and P_{80}	< 0.001	< 0.001	< 0.001	P0	1.50	1.61	1.80
		P_{40} vs. P_{80}	< 0.001	< 0.001	0.41	P1	1.82	1.98	2.14
						P2	2.12	2.34	2.20
Talagang	2007-2008	P_0 vs. P_{40} and P_{80}	< 0.001	< 0.001	< 0.001	P0	0.82	0.89	0.93
		P_{40} vs. P_{80}	< 0.001	< 0.001	< 0.001	P1	0.97	1.06	1.13
						P2	1.12	1.21	1.32
Data pooled across locations and years		P_0 vs. P_1 and P_2	< 0.001	< 0.001	< 0.001	P0	0.98	1.05	1.12
		P_1 vs. P_2	< 0.001	< 0.001	0.29	P1	1.18	1.29	1.38
						P2	1.32	1.44	1.44

Chickpea seed yield (Mg ha^{-1})

[a]P_0, P_1 and P_2 stand for application of 0, 40 and 80 kg P_2O_5 ha^{-1}; and S_0, S_{15} and S_{30} for 0, 15 and 30 kg S ha^{-1}

Table V: Seed yield (Mg ha^{-1}) as function of sulfur levels from two sulfur sources.

	Chakwal 2006-07	Chakwal Mean	Talagang 2007-08	Overall Mean
Gypsum (kg S ha^{-1})				
0	1.11 d	0.93 d	0.97 d	1.15 d
15	1.20 c	0.99 c	1.02 c	1.22 c
30	1.24 b	1.03 b	1.09 b	1.27 b
Ammonium sulfate (kg S ha^{-1})				
0	1.10 d	0.93 d	0.97 d	1.17 d
15	1.24 b	1.03 b	1.07 b	1.29 b
30	1.27 a	1.05 a	1.15 a	1.36 a

Means with different letters differ significantly according to Least Significant Difference (LSD) test (*P<0.05*)

The S source by S level interaction was significant (Table III). It was observed from data pooled over location and year that application of 30 kg S ha^{-1} in the form of AS was superior to same level of S application in the form of gypsum (Table V). It was also observed that application of 30 kg S ha^{-1} in the form of gypsum was statistically similar

Table VI: Interaction effect between phosphorus and sulfur application regarding seed yield

Effect	Chakwal			Talagang			Overall Mean
	2006-07	2007-08	Mean	2006-07	2007-08	Mean	
Increase due to sole P over control							
with 40 kg P_2O_5 ha^{-1}	240	98	169	314	144	229	199
with 80 kg P_2O_5 ha^{-1}	290	157	223	616	296	456	340
Increase due to sole S over control							
with 15 kg S ha^{-1}	49	56	52	110	63	86	70
with 30 kg S ha^{-1}	86	85	85	299	101	200	143
Increase due to combined P and S							
with 40 kg P_2O_5 and 15 kg S ha^{-1}	362	171	266	476	232	354	310
with 80 kg P_2O_5 and 30 kg S ha^{-1}	434	232	332	691	499	595	464
Type of interaction							
with 40 kg P_2O_5 and 15 kg S ha^{-1}	synergistic	synergistic	synergistic	synergistic	synergistic	synergistic	synergistic
with 80 kg P_2O_5 and 30 kg S ha^{-1}	synergistic	antagonistic	synergistic	antagonistic	synergistic	antagonistic	antagonistic

Table VII: Agronomic efficiency as function of phosphorus and sulfur levels

Effect	Chakwal		Mean	Talagang		Mean	Over all Mean
	2006-07	2007-08		2006-07	2007-08		
P levels (kg P_2O_5 ha^{-1})							
40	7.5	2.8	5.3	8.5	4.3	6.3	5.8
80	4.3	1.9	3.0	7.3	4.1	5.8	4.5
S levels (Kg S ha^{-1})							
15	7.3	4.0	5.7	11.3	4.7	8.0	7.3
30	4.7	3.0	3.8	8.0	5.0	6.7	5.3

Table VIII: Effect of different phosphorus and sulfur levels on value cost ratio (data pooled across years)

Treatments	Value cost ratio (VCR)		
	Chakwal	Talagang	Mean
P levels (kg P_2O_5 ha^{-1})			
0	-	-	-
40	5.85	7.28	6.57
80	3.51	6.49	5.00
Gypsum (kg S ha^{-1})			
0	-	-	-
15	11.44	17.5	14.47
30	8.85	12.68	10.77
Ammonium sulfate (kg S ha^{-1})			
0	-	-	-
15	5.34	7.48	6.41
30	3.41	6.42	4.92
P × S Interaction			
P_0S_0	-	-	-
P_0S_{15}	4.23	7.08	5.66
P_0S_{30}	3.46	8.14	5.80
$P_{40}S_0$	4.8	6.52	5.66
$P_{40}S_{15}$	6.36	7.47	6.92
$P_{40}S_{30}$	5.66	7.89	6.78
$P_{80}S_0$	3.18	6.48	4.83
$P_{80}S_{15}$	3.91	7.34	5.63
$P_{80}S_{30}$	3.51	6.27	4.89

Price of triple super phosphate, ammonium sulfate and gypsum was taken as 716,779 and 100 rupees per bag of 50 kg, while that of chickpea seed was taken as 1416 rupees per 40 kg

to application of 15 kg S ha^{-1} in the form of AS.

Data was also analyzed to make a comparison between the additive effects of combined application of P and S with those of individual ones. It was observed that combined application of lower level of P (40 kg P_2O_5 ha^{-1}) and S (15 kg S ha^{-1}) had positive or synergistic effect on seed yield at both the location during the whole period of study (Table VI). The effect of combined application of higher level of P (80 kg P_2O_5 ha^{-1}) and S (30 kg S ha^{-1}) was positive or synergistic during first year at Talagang and second year at Chakwal but when data were pooled across location and year only then it was negative or antagonistic.

Agronomic efficiency was in range of 1.9 to 8.5 for P, while 3.0 to 11.3 for S (Table VII). It was higher at Talagang as compared to Chakwal for both P and S. Similarly it was higher during first year as compared to second year. Lower rates of nutrient application had higher agronomic efficiency as compared to higher ones.

It was observed that VCR was higher at Talagang as compared to Chakwal (Table VIII). It was higher at lower level of nutrient application as compared to higher level. Gypsum application had higher VCR as compared to AS due to relatively higher prices of AS. Among different combinations of P and S, maximum VCR (6.92) was recorded in $P_{40}S_{15}$, which was followed by $P_{40}S_{30}$ (6.78). Treatment $P_{80}S_0$ had the lowest VCR (4.83).

DISCUSSION

There was significant difference between years and locations in respect of seed yield (Table II). Seed yield was higher at Talagang as compared to Chakwal. This was due to difference in climatic conditions as well as fertility status of soils of two locations. Higher moisture availability at the time of sowing resulted in better germination and ultimately good crop stand and higher nutrient uptake at Talagang. Intensity of frost was less at Talagang as compared to Chakwal. Another reason might be that well drained soils are suitable for the production of chickpea (Khalil & Jan, 2002). Soil at Talagang was well drained being loamy sand compared to sandy loam soil of Chakwal (Table I). Similarly, seed yield was higher during first year as compared to second year. This was due to favorable climatic conditions during first year especially timely rainfall through out growing season. Although, there was abundant moisture supply at the time of sowing during second year, germination and crop growth was better at the start, but there was incidence of frost at flowering stage accompanied by prolonged drought, which adversely affected crop growth and yield. Total rainfall during second year from October 2007 to March 2008 was 90 mm and 30 mm at Chakwal and Talagang, respectively, which was 77 and 92 percent less than first year (385 & 362 mm). Low temperatures slow down the rate of leaf extension and increase the time to reach full crop canopy cover (Hussain, 1998). Similar results were also reported by Khalid *et al.* (2009) and Hayat and Ali (2010). They observed that growth and yield of crop was better during cropping season of higher rainfall due to abundant supply of moisture, when crop was grown under rainfed conditions.

Phosphorus application resulted in significant increase in seed yield. These results are in line with the findings of Aslam *et al.* (2000), who recorded 57% (770 kg ha^{-1}) increase in seed yield with application of 80 kg P_2O_5 ha^{-1} under rainfed conditions. However, Khan (2002) reported 75% increase in chickpea seed yield over control with application of 90 kg P_2O_5 ha^{-1}, which was much higher than observed in our study (34%). Higher response might be due to irrigated condition, where response to nutrient application is generally higher than rainfed conditions (Ahmad & Rashid, 2003). Increase in seed yield due to application of S confirms the finding of Sharma and Arora (2008) and Gunes *et al.* (2009). Sulfur and phosphorus interaction was positive at lower rate of nutrient application and negative at higher rate. Tiwari and Gupta (2006) observed that on a soil deficient in both and P and S, there was no interaction between P and S in terms of seed yield at $P_{40}S_{20}$, positive at $P_{60}S_{40}$ and negative at $P_{80}S_{60}$, when pigeon pea was used as test crop. Randhawa and Arora (2000) observed a highly significant positive interaction between P and S in terms of P uptake leading to higher seed yield of wheat at low rate of S application. Higher rates of S application caused antagonistic effect. Contrary to these findings, Paliwal *et al.* (2009) observed that interaction of P and S exhibited strong synergistic relationship regarding soybean nutrition on Alfisol deficient in both P and S. Interaction between P and S occurs mainly due to two reasons. Firstly, P and S occurs in soil in the form of phosphate (PO_4^{-3}) and sulfate (SO_4^{-2}), which are anions and compete for adsorption on exchange sites in soil. However, adsorption strength of PO_4^{-3} is more than that of SO_4^{-2} and presence of PO_4^{-3} results in reduction in SO_4^{-2} adsorption and accelerates downward movement (Abdin *et al.*, 2003). Secondly, application of S fertilizers to calcareous soils results in reduction in pH although temporarily and locally. This prevents the conversion of primary orthophosphate ($H_2PO_4^-$) and secondary orthophosphate (HPO_4^{-2}) into PO_4^{-3} thus increasing the availability of P for plant uptake (Taalab *et al.*, 2008).

A comparison of two S sources indicated that effect of application of 30 kg S ha^{-1} in the form of gypsum was statistically similar to 15 kg S ha^{-1} in the form of AS, but significantly lower than 30 kg S ha^{-1} (Table IV). Lower response of plant to gypsum application as compared to AS may be due to slow release of S from this source (Girma *et al.*, 2005). Ghosh *et al.* (2000) drawn conclusion after a series of trials that, where immediate relief from S deficiency is necessary, readily soluble sources like AS out classed less soluble sources such as gypsum. They also observed that in calcareous soils, gypsum was less effective as compared to soluble sources like AS. Agronomic efficiency decreased with increasing rate of nutrient application. Similar trend has also been reported earlier for wheat crop (Jain & Dahama, 2006). Kumar *et al.* (2011) reported agronomic efficiency of S in range of 4.0 to 5.8 for Indian mustard grown under rainfed condition.

Economic analysis showed that VCR increased as a result of combined application of P and S as compared to their sole application (Table VIII). Therefore keeping in view the economic analysis and all other factors such as yield increase and agronomic efficiency, sulfur should applied along with phosphorus preferably in the form of gypsum and nutrient combination of either $P_{80}S_{15}$ or $P_{40}S_{30}$ is suitable. Nutrient combination of $P_{80}S_{30}$ is not advisable as there is antagonistic relation between P and S in terms of seed yield of chickpea at this fertilizer application rate.

In conclusion, application of P and S resulted in significant increase in seed yield at both the locations. Interaction between P and S was positive at lower rate and negative at higher rate of nutrient application. Fertilizer combinations of $P_{80}S_{15}$ or $P_{40}S_{30}$ are more suitable than

$P_{80}S_{30}$ for chickpea grown under rainfed conditions. Moreover, S should be included in nutrient management program in order to get maximum yield of chickpea under rainfed conditions.

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