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RESPONSE OF CHICKPEA TO VARIOUS LEVELS OF PHOSPHORUS AND SULPHUR UNDER RAINFED CONDITIONS IN PAKISTAN

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ABSTRACT

Balanced fertilizer use is the key to get maximum crop yield. It is very important to work out optimum level of each nutrient application since there may be positive (synergistic) or negative (antagonistic) interaction between them. A field experiment was conducted at Barani Agriculture Research Institute Chakwal, Pakistan for two years to assess the seed yield, agronomic efficiency and nutrient recovery by chickpea (*Cicer arietinum* L.). The treatments comprised three levels (0, 40 and 80 kg P_2O_5 ha^{-1}) of phosphorus and three levels (0, 15 and 30 kg S ha^{-1}) of sulphur from two sulphur sources (gypsum and ammonium sulphate) in different combinations. The trial was laid out according to randomised complete block design with split-split plot arrangement. Application of phosphorus and sulphur resulted in significant increase in seed yield by 29 and 12% over control, respectively. The economic optimum dose of phosphorus and sulphur, as calculated from quadratic response equations ranged from 56 to 58 and 32 to 53 kg ha^{-1} respectively. Effect of combined application of phosphorus and sulphur was synergistic at both nutrient application rates of $P_{40}S_{15}$ and $P_{80}S_{30}$. Agronomic efficiency and sulphur recovery were higher due to combined application of phosphorus and sulphur as compared to individual ones. Phosphorus recovery was higher at lower level of phosphorus (40 kg P_2O_5 ha^{-1}) as compared to higher level (80 kg P_2O_5 ha^{-1}). Value cost ratio was less than 2 for sole application of higher level of phosphorus. A fertilizer combination of $P_{80}S_{30}$ was more economical and cost effective.

Key words: Sulphur sources, economic optimum dose, agronomic efficiency, value cost ratio.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is an important pulse crop in rainfed areas of Pakistan. Average chickpea yield in Pakistan is much lower than in 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). A number of factors, including genetic and environmental ones, are responsible for this low yield and imbalanced fertilization is the key among them.

Phosphorus (P) and sulphur (S) are major nutrient elements for grain legumes. In many soil types, P is the most limiting nutrient for the production of crops (Jiang et al., 2006). It plays primary role in many of the physiological processes such as the utilization of sugar and starch, photosynthesis, energy storage and transfer. Legumes generally have higher P requirement because the process of symbiotic nitrogen (N) fixation consumes a lot of energy (Schulze et al., 2006). Sulphur is becoming deficient in our soil due to use of high grade S free fertilizers, cultivation of high yielding varieties and lack of industrial activity/deposition (Scherer, 2009). Soils of rainfed area in Pakistan are particularly deficient in S (Khalid et al., 2009a). Sulphur is a vital part of the ferredoxin, an iron-sulphur protein occurring in the chloroplasts. Ferredoxin has a significant role in nitrogen dioxide and sulphate reduction and assimilation of N by root nodule and free living N-fixing soil bacteria (Scherer, 2008, Scherer et al., 2008).

In crop plants, the nutrient interactions are generally measured in respect of growth response and change in concentration and uptake of nutrients. Interaction between two

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nutrients is said to be positive or synergistic when combined application of two nutrients results in an increase in yield that is more than their sole or individual application. Similarly, if addition of the two nutrients together produces lower yield as compared to individual ones, the interaction is negative (antagonistic). When there is no change, there is no interaction (Fageria, 2001). A better understanding of nutrient interaction is helpful in maximizing fertilizer use efficiency and net profit. This has become particularly important in the scenario of increasing prices of phosphate fertilizer.

In Pakistan, work done regarding crop response to S application is limited to oilseeds and their oil content only (Islam et al., 2009). Research work regarding interaction of P and S and their role in legume's growth is very scarce. Furthermore, phosphate fertilizers have become very costly and their efficiency is very low in rainfed agriculture. Economic and judicious use of this precious input has become very important. Therefore, the present study was conducted to assess the interactive effect of sulphur and phosphorus application on seed yield, agronomic efficiency and nutrient recovery using chickpea as test crop under rainfed conditions of northern Punjab, Pakistan.

MATERIAL AND METHODS

Field experiments were conducted using chickpea cultivar Balkassar 2000 at Barani Agricultural Research Institute (BARI), Chakwal, during crop growing season 2006-2007 and 2007-2008. Physical and chemical properties of the experimental site are shown in Table 1. The trial was laid out in randomized complete block design with split-split plot arrangement (plot size of 1.5 × 3.5 m) 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 and 80 kg ha^{-1}) and S rates (0, 15and 30 kg ha^{-1}) from two S sources (gypsum and ammonium sulphate). Starter dose (26 kg ha^{-1}) of 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 sulphate (AS). Phosphorus was applied in the form of triple super phosphate (TSP). All the treatments were replicated three times. Chickpea crop was sown with 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 90 mm during crop growing season 2006-2007 and 2007-2008.

At physiological 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 were recorded for seed, straw and dry matter yield. The quadratic response equation was found to be best fit to define the relationship between x and Y as shown below:

$$Y = a + bx + cx^2$$

where Y= seed yield (kg ha^{-1}); x = level of P or S (kg ha^{-1}); a, b and c are constants of quadratic response equation. The economic optimum dose (EOD) of P or S (kg ha^{-1}) was computed by using the following equation:

$$Xopt(EOD) = \{q/p-b\}/2c$$

where b and c are the two constants of the quadratic response function and q is the per unit cost of P or S and p is the price of one unit of seed yield. The yield at EOD of P or S was computed by using quadratic equation:

$$Y = a + bx + cx^2$$

where Y = seed yield (kg ha^{-1}) at EOD; x = EOD of P or S (kg ha^{-1}); a, b and c are constants of quadratic response equation. The response to economic optimum dose (REOD) of S was computed by using the equation:

$$REOD = (Yopt – Ycont)/Xopt$$

where Yopt =Yield computed at EOD; Ycont = Yield in control plot; Xopt = Economic optimum dose.

Nutrient interactions (synergistic or antagonistic) were calculated by comparing the increase in yield (in terms of kg ha^{-1} over control) due to combined P and S application, with that of individual/separate applications (Fageria, 2001).

Representative samples of 100 g from both seed and straw were collected from bulk sample, oven dried and ground and analysed for P (Ryan et al., 2001) and S content (Verma, 1977). Nutrient uptake was determined by multiplying the respective nutrient concentration with dry matter yield.

Nutrient recovery of applied P and S fertilizer was calculated by following formula and expressed on percentage basis (Craswell, 1987).

Apparent Nutrient Recovery = (Nutrient $Uptake_F$ - Nutrient $Uptake_C$/Nutrient applied) x 100

Nutrient $Uptake_F$ = Nutrient uptake in fertilized plot (kg ha^{-1})

Nutrient $Uptake_c$ = Nutrient uptake in unfertilised (control) plot

Nutrient applied = Fertilizer rate (kg ha^{-1})

Table 1. Location, rainfall and physical and chemical properties of soil of experimental site

Parameter	Unit	Value
Latitude	N	32.5°
Longitude	E	72.4°
Mean annual rainfall (1979-2009)	mm	630
Cropping season (October to March) rainfall during (i) 2006-07 (ii) 2007-08	mm	 385 90
Sand	%	69
Silt	%	21
Clay	%	10
Texture	-	Sandy loam
pH	-	7.6
ECe	dSm^{-1}	0.32
Total organic carbon	mg g^{-1}	3.7
$CaCO_3$	%	5.2
Total N	%	0.02
NO_3-N (AB-DTPA extractable)	µg g^{-1}	11.2
Phosphorus (AB-DTPA extractable)	µg g^{-1}	3.0
Sulphate- Sulphur ($CaCl_2$ extractable)	µg g^{-1}	6.4
Zinc (AB-DTPA extractable)	µg g^{-1}	0.75
Copper (AB-DTPA extractable)	µg g^{-1}	1.21
Iron (AB-DTPA extractable)	µg g^{-1}	7.82
Manganese (AB-DTPA extractable)	µg g^{-1}	2.98

Agronomic efficiency was calculated by dividing the increase in yield over control by amount of nutrient applied (Ahmad and Rashid, 2003).

The economics of applied fertilizer was measured by value cost ratio (VCR). The VCR value was calculated by following formula (Ahmad and Rashid, 2003).

VCR = Value of yield increase obtained/ Total cost of fertilizer.

Prices of input and output prevailing in the market during fiscal year 2007-2008 were taken into account for economic analysis (NFDC, 2009).

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.

RESULTS AND DISCUSSION

Seed yield

There was significant increase in seed yield of chickpea with P application (Table 2). Seed yield increased from 0.84 to 1.08 Mg ha^{-1} (data pooled over years) as P rate was increased from 0 to 80 kg P_2O_5 ha^{-1}. Difference between lower (40 kg P_2O_5 ha^{-1}) and higher level (80 kg P_2O_5 ha^{-1}) of P was significant. There was 29% increase in seed yield, which is in accordance with findings of Hayat and Ali (2010) who reported 10% increase in seed yield of mung bean due to application of 80 kg P_2O_5 ha^{-1} under similar climatic conditions. However, an increase upto 75% was reported in seed yield of chickpea due to application of 90 kg P_2O_5 ha^{-1} under irrigated condition (Khan, 2002). This difference might be due to the fact that fertilizer use efficiency and response to nutrient application is generally low under rainfed conditions due to drought stress (Ahmad and Rashid, 2003).

Table 2. Seed yield and agronomic efficiency as function of P and S levels and S sources

Effect	Seed yield (Mg ha^{-1})			Agronomic efficiency		
	2006-2007	2007-2008	Mean	2006-2007	2007-2008	Mean
P levels (kg P_2O_5 ha^{-1})						
0	0.98 c	0.70 c	0.84 c	-	-	-
40	1.28 b	0.81 b	1.05 b	7.5	2.8	5.3
80	1.32 a	0.85 a	1.08 a	4.3	1.9	3.0
Significance level	**	**	**	-	-	-
LSD value	0.02	0.03	0.01	-	-	-
S sources						
Gypsum	1.18	0.78	0.98 b	-	-	-
Ammonium sulphate	1.20	0.80	1.00 a	-	-	-
Significance level	NS	NS	**	-	-	-
S levels (kg S ha^{-1})						
0	1.11 c	0.74 c	0.93 c	-	-	-
15	1.22 b	0.80 b	1.00 b	7.3	4.0	5.7
30	1.25 a	0.83 a	1.04 a	4.7	3.0	3.8
Significance level	**	**	**			
LSD value	0.02	0.02	0.01	-	-	-
F values and significance levels of interactions						
P × S sources	4.0 ^{NS}	0.8 ^{NS}	2.4 ^{NS}	-	-	-
P × S levels	10.9 **	0.5 ^{NS}	4.1 **	-	-	-
S sources × S levels	3.6 *	1.3 ^{NS}	3.8 *	-	-	-
P × S sources × S levels	2.3 ^{NS}	0.2 ^{NS}	0.7 ^{NS}	-	-	-

Different letters in the same column denote significant differences among treatments (P≤0.05). The values correspond to averages of three replicates. NS stands for non significant difference;
* and ** denote significance at P≤0.05 and P≤0.01 levels, respectively.

A trend similar to P was also observed for S regarding seed yield (Table 2). There was an increase up to 12% in the seed yield of chickpea due to application of 30 kg S ha^{-1}. Hussain (2010) reported 15% increase in seed yield of soybean (*Glycine max*) due to application of 30 kg S ha^{-1} under rainfed conditions. The two S sources (gypsum and AS) differed from each other in their effect on seed yield (Table 2), which is contrary to the findings of Khalid et al. (2009b) who observed non significant differences between gypsum, AS and single super phosphate in respect of seed yield of *Brassica napus*. It was also observed 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 (Table 6). Suitability of each source of S varies according to climatic conditions, soil type, and crop S requirements. For crops requiring immediate relief from S deficiency, AS is superior, while on coarse textured soils and under high rainfall conditions, gypsum is better due to slow release of S (Tiwari and Gupta, 2006). The P by S level interaction was significant for seed yield when data was pooled across years (Table 2). The maximum seed yield was recorded in $P_{80}S_{30}$, which was at par with $P_{80}S_{15}$ and $P_{40}S_{30}$, while the lowest yield was recorded in control (Table 5). Increasing rate of S application at same rate of P resulted in increase in seed yield, which can be explained by an improvement in overall growth processes of plant, as a result of balanced supply of nutrients.

The response of chickpea to P and S was quadratic in both years (Table 3). The economic optimum dose of P and S ranged between 56 to 58 and 32 to 53 kg ha^{-1} respectively. Extent of response in terms of b value and response at EOD (kg seed yield kg^{-1} S) was higher for P during first year as compared to second year. This might be due to more favorable climatic conditions especially rainfall (Table 1).

A comparison of effects of individual and combined nutrient application showed that combined effect of P and S was more than individual effects, both at lower ($P_{40}S_{15}$) and higher levels ($P_{80}S_{30}$) of nutrient application, when data was pooled over years (Table 4). Thus, there was positive or synergistic interaction between P and S. Similar results were reported by Jaggi and Sharma (1999). They observed that combined application of P and S at their highest rate produced maximum yield of raya (*Brassica juncea*) and there was positive significant interaction between P and S. Paliwal et al. (2009) also observed synergistic relation between P and S up to $P_{60}S_{40}$ using soybean (*Glycine max*) as test crop. Hence, type of interaction between P and S varies with soil fertility level, climatic conditions, test crop and rate of nutrient application.

Table 3. Response equation, economic optimum dose and seed yield at economic optimum dose of chickpea as function of phosphorus and sulphur

Treatments	Response Equation (kg ha^{-1})	R^2	Economic Optimum Dose (EOD) (kg ha^{-1})	Yield at EOD (kg ha^{-1})	Response at EOD (kg seed yield kg^{-1} P or S)
2006-2007					
Phosphorus	$Y = 934 + 8.41X - 0.059X^2$	95	58	1223	5.00
Sulphur	$Y = 934 + 3.66X - 0.027X^2$	67	53	1051	2.23
2007-2008					
Phosphorus	$Y = 657 + 2.94X - 0.012X^2$	91	56	784	2.25
Sulphur	$Y = 657 + 4.58X - 0.058X^2$	71	32	744	2.69

Table 4. Interaction effect between phosphorus and sulphur application regarding seed yield

Effect	2006-2007 (kg ha^{-1})	2007-2008 (kg ha^{-1})	Mean (kg ha^{-1})
Increase due to sole P over control:			
- with 40 kg P_2O_5 ha^{-1}	240	98	169
- with 80 kg P_2O_5 ha^{-1}	290	157	223
Increase due to sole S over control:			
- with 15 kg S ha^{-1}	49	56	52
- with 30 kg S ha^{-1}	86	85	85
Increase due to combined P and S:			
- with 40 kg P_2O_5 and 15 kg S ha^{-1}	362	171	266
- with 80 kg P_2O_5 and 30 kg S ha^{-1}	434	232	332
Type of interaction:			
- with 40 kg P_2O_5 and 15 kg S ha^{-1}	synergistic	synergistic	synergistic
- with 80 kg P_2O_5 and 30 kg S ha^{-1}	synergistic	antagonistic	synergistic

Agronomic efficiency and nutrient recovery

Agronomic efficiency declined with increase in nutrient application rate (Table 2). It was higher during first year as compared to second year as a result of better climatic conditions. Agronomic efficiency was higher due to combined application of P and S as compared to their sole application (Table 5). These results corroborate with the findings of Kumar et al. (2011) who also observed reduction in agronomic efficiency of nutrients with increase in their application rate.

Lower rates of S application resulted in higher nutrient recovery (Table 6). Combined application of S and P resulted in increase in S recovery (Table 5). Maximum and minimum sulphur recovery was recorded in $P_{80}S_{15}$ and P_0S_{15}, respectively. Sulphur recovery for AS was higher as compared to gypsum (Table 6) which may be attributed to its higher solubility resulting in higher S availability for plant uptake (Ghosh et al*.,* 2000). In the present study, average S recovery was in range of 2.0 to 6.9 percent, which is close to the value of 3 percent reported for chickpea (Tandon, 1991). Sulphur fertilizer recovery is governed by a number of factors such as initial S status of soil, rate of S application and type of crop.

Table 5. Seed yield, agronomic efficiency and sulphur recovery as a function of phosphorus within each sulphur level

Treatments	Seed yield (Mg ha^{-1})		Agronomic efficiency			Sulphur recovery (%)		
	2006-2007	Mean	2006-2007	2007-2008	Mean	2006-2007	2007-2008	Mean
P_0S_0	0.93 g	0.79 g	-	-	-	-	-	-
P_0S_{15}	0.98 f	0.85 f	3.2	3.7	3.5	1.7	2.3	2.0
P_0S_{30}	1.02 e	0.88 e	2.8	2.8	2.9	2.2	2.1	2.1
$P_{40}S_0$	1.17 d	0.96 d	6.0	2.4	4.2	-	-	-
$P_{40}S_{15}$	1.30 b	1.06 b	6.6	3.1	4.9	7.7	3.9	5.8
$P_{40}S_{30}$	1.37 a	1.11 a	6.2	2.9	4.6	6.8	3.5	5.2
$P_{80}S_0$	1.22 c	1.02 c	3.6	2.0	2.8	-	-	-
$P_{80}S_{15}$	1.38 a	1.11 a	4.7	2.1	3.4	9.8	4	6.9
$P_{80}S_{30}$	1.37 a	1.12 a	3.9	2.1	3.0	4.4	3.4	3.9

Different letters in the same column denote significant differences among treatments ($P \leq 0.05$).
The values correspond to averages of three replicates.

Table 6. Seed yield and sulphur recovery as function of sulphur levels from two sulphur sources

Sulphur source	Seed yield (Mg ha^{-1})		Sulphur recovery (%)		
	2006-2007	Mean	2006-2007	2007-2008	Mean
Gypsum (kg S ha^{-1})					
0	1.11 d	0.93 d	-	-	-
15	1.20 c	0.99 c	5.1	2.5	3.8
30	1.24 b	1.03 b	3.2	2.4	2.8
Ammonium sulphate (kg S ha^{-1})					
0	1.10 d	0.93 d	-	-	-
15	1.24 b	1.03 b	7.8	4.3	6.0
30	1.27 a	1.05 a	5.7	3.6	4.7

Different letters in the same column denote significant differences among treatments ($P \leq 0.05$).
The values correspond to averages of three replicates.

Level of N, P and K application may also have an effect on recovery of added S, as these have influence on overall crop growth (Hedge and Murthy, 2005). These results are also in line with the findings of Khalid (2007) who observed higher S recovery (29.2%) due to AS application as compared to gypsum (14.4%) at S application rate of 30 kg ha^{-1}. Lower S recovery in present study may be due to the fact that S requirement of pulses is lower as compared to oilseed crops and sulphur recovery of 8-10% has been reported for pulses (Hedge and Murthy, 2005). Furthermore, adverse environmental conditions, particularly during second year of the study resulted in less dry matter production and ultimately low S uptake and S recovery. Increase in S recovery due to P application may be owed to significant improvement in dry matter production (Hedge and Murthy, 2005).

Table 7. Phosphorus recovery as a function of phosphorus doses within each sulphur level

Treatments	2006-2007	2007-2008	Mean
P levels:			
0	-	-	-
40	7.96	2.75	5.33
80	5.15	2.61	3.87
P × S levels interaction:			
P_0S_0	-	-	-
P_0S_{15}	6.24	2.92	4.58
P_0S_{30}	4.58	2.52	3.55
$P_{40}S_0$	-	-	-
$P_{40}S_{15}$	8.59	3.09	5.84
$P_{40}S_{30}$	6.56	3.12	4.84
$P_{80}S_0$	-	-	-
$P_{80}S_{15}$	8.93	2.29	5.61
$P_{80}S_{30}$	4.30	2.21	3.26

Phosphorus recovery was higher at lower level of P application (40 kg P_2O_5 ha^{-1}) as compared to higher one (Table 7). Data pooled across years indicated that P recovery was maximum in $P_{40}S_{15}$ and minimum in $P_{80}S_{30}$. Phosphorus recovery in range of 3.3 to 5.8 percent was much lower than reported value of 10 to 25 percent, which may be due to the fact that crop was grown under rainfed conditions (Ahmad and Rashid, 2003).

Fertilizer use efficiency in rainfed areas is comparatively lower than in irrigated agriculture, because of drought stress at critical growth stages. Phosphorus recovery in range of 1.6 to 13.3 percent has been reported in pot experiments using soybean as test crop (Jin et al., 2006). However, under field condition in irrigated area of Pakistan, P use efficiency has been reported to be in range of 5.2 to 25.7 percent for wheat and 3.9 to 21.3 percent for rice (Rehman, 2004).

Economic analysis

Value cost ratio is the rate of return on money spent on fertilizers. If VCR is greater than one, the fertilizer use will be profitable. A VCR of 2 represents a 100 percent return on money invested on fertilizer. For high technology, recommended VCR is 2, as it ensures a good net return.

At VCR lower than two, farmer's margin of return becomes low and there is risk of losing money if there is poor management or bad weather. Due to risk factors, VCR of 2 is considered satisfactory. In our study, VCR value was higher for S as compared to P and among S sources; higher VCR value was recorded for gypsum as compared to AS (Table 8). Among different P and S combinations, sole application of higher level of P resulted in VCR less than 2.

Table 8. Value cost ratio as function of phosphorus and sulphur levels

Treatments	2006-2007	2007-2008	Mean
Phosphorus levels (kg P_2O_5 ha^{-1}):			
0	-	-	-
40	4.75	1.75	3.25
80	2.71	1.19	1.95
Gypsum (kg S ha^{-1}):			
0	-	-	-
15	14.33	7.17	10.83
30	10.17	6.50	8.33
Ammonium sulphate (kg S ha^{-1}):			
0	-	-	-
15	6.91	3.93	5.37
30	4.23	2.69	3.43
P × S levels interaction:			
P_0S_0	-	-	-
P_0S_{15}	3.88	4.53	4.20
P_0S_{30}	3.43	3.43	3.43
$P_{40}S_0$	3.79	1.55	2.67
$P_{40}S_{15}$	4.76	2.26	3.51
$P_{40}S_{30}$	4.91	2.33	3.62
$P_{80}S_0$	2.28	1.24	1.76
$P_{80}S_{15}$	3.18	1.47	2.32
$P_{80}S_{30}$	2.85	1.54	2.19

*For economic analysis, price of urea, TSP, gypsum and ammonium sulphate was taken as Rs. 581, 1458, 120 and 867 per bag of 50 kg while that of chickpea as Rs. 1600 per 40 kg.

CONCLUSIONS

Application of P and S resulted in significant increase in seed yield. Interaction between P and S was positive at both lower and higher rate of nutrient application. Economic analysis showed that fertilizer combination of $P_{80}S_{30}$ was profitable as value cost ratio was higher than 2. Sulphur should be included in nutrient management programme in order to get maximum yield of pulses. This will result in increased fertilizer use efficiency and saving of this precious and costly input. However, further experimentation is needed to make generalized recommendation regarding exact ratio of P and S.

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