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ABSTRACT

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Keywords: phosphorous, sulphur, sulphur sources, chickpea, yield.
Classification: For Code: 039999, 030301
Language: English

London Journals Press

LJP Copyright ID: 965622
ISBN 10: 1537586327
ISBN 13: 978-1537586328

London Journal of Research in Science: Natural and Formal

135UK

Volume 17 | Issue 1 | Compilation 1.0

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Appropriate fertilizer use is imperative to acquire highest crop yield. It is very essential to find out best level of each nutrient appliance as there might be affirmative (synergistic) or depressing (antagonistic) interaction among them. A field research was performed at Agriculture Research Station Harichand, Pakistan for two years to evaluate seed yield, agronomic efficacy and recovery of nutrient by chickpea (Cicer arietinum L.). The treatments involves three levels (0, 50 and 100 kg P_2O_5 ha^{-1}) of phosphorus and three levels (0, 20 and 40 kg S ha^{-1}) of sulphur from the two sulphur sources (gypsum and ammonium sulphate) in diverse combinations. The assessment was put down according to randomized complete block design with the split-split plot arrangement. Seed yield was significantly increased by the fertilization of phosphorous and sulphur by 30 and 13% against control, respectively. The economic optimal amount of phosphorus and sulphur, as estimated from quadratic response equations ranged from 57 to 59 and 33 to 54 kg ha^{-1} correspondingly. Consequence of pooled application of phosphorus and sulphur was synergistic at the both nutrient fertilization rates of $P_{40}S_{15}$ and $P_{100}S_{40}$. Agronomic efficacy and recovery of sulphur were elevated due to pooled application of phosphorus and sulphur as over the individual ones. Phosphorus recovery was elevated at inferior level of phosphorus (50 kg P_2O_5 ha^{-1}) in contrast to superior level (100 kg P_2O_5 ha^{-1}). The value cost ratio was fewer than 2 for sole application of superior level of phosphorus. The fertilization level of $P_{100}S_{40}$ was more economic and cost effective.

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II. INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a significant pulse crop in arid areas of Pakistan. During 2010-11, gram was cultured on 1094 thousand hectare with total production of 760 thousand tons, which was 60% elevated as over preceding year (Anonymous, 2011). This little average seed yield of gram in Pakistan is small as over other gram growing countries of the world like China (3333 kg ha^{-1}), Lebanon (2310 kg ha^{-1}), Tunisia (1968 kg ha^{-1}) and Egypt (1790 kg ha^{-1}) (Anonymous, 2010). This is possibly due to the reality that gram is cultured on marginal lands. A number of aspects, counting genetic and environmental ones, are accountable for this stumpy yield and excessive fertilization is the vital between them.

Phosphorus (P) and sulphur (S) are foremost nutrient elements for the grain legumes. In numerous soil categories, P is the mainly restraining nutrient for the production of the crops (Jiang et al., 2006). It acts crucial role in numerous of the physiological developments such as the exploitation of the sugar and starch, photosynthesis, energy storage and transfer. Legumes usually have advanced P requisite as the

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procedure of symbiotic nitrogen (N) fixation devours a lot of energy (Schulze et al., 2006). Sulphur is becoming scarce in our soil due to exploit of high grade S free fertilizers, nurturing of towering yielding varieties and lack of industrial action/deposition (Scherer, 2009). Soils of the rainfed area in the Pakistan are predominantly underprovided in S (Khalid et al., 2009a). Sulphur is a fundamental element of the ferredoxin, an iron-sulphur protein taking place in the chloroplasts. Ferredoxin has a considerable role in nitrogen dioxide and sulphate reduction and absorption of N by root nodule and free living N-fixing soil bacteria (Scherer, 2008, Scherer et al., 2008).

In crop plants, the nutrient exchanges are usually calculated in respect of growth response and alter in concentration and uptake of nutrients. Interaction among two nutrients is said to be affirmative or synergistic when pooled application of two nutrients consequences in an amplify in yield that is more than their individual application. Likewise, if addition of the two nutrients collectively manufactured inferior yield over individual ones, the interaction is pessimistic (antagonistic). When there is no alteration, there is no interaction (Fageria, 2001). A superior understanding of nutrient interaction is supportive in exploiting fertilizer use efficiency and net income. This has become predominantly significant in the circumstances of rising prices of the phosphate fertilizer.

In Pakistan, effort done concerning crop reply to S fertilization is restricted to oilseeds and their oil constituents only (Islam et al., 2009). The research effort concerning interaction of P and S and their role in legume's development is very sparse. Moreover, phosphate fertilizers have become extremely pricey and their effectiveness is very little in rainfed farming. Cost-effective and cautious utilization of this valuable input has become incredibly significant. Thus, the current work was accomplished to evaluate the interactive outcome of sulphur and phosphorus fertilization on seed yield, agronomic efficacy and nutrient return using chickpea as check crop under rainfed environments of Khyber Pakhtunkhwa, Pakistan.

III. Materials and Methods

Field tests were performed using chickpea cultivar Karak-1 at Agricultural Research Station Harichand, during crop growing season 2014-2015 and 2015-2016. Physical and chemical properties of the investigational place are publicized in Table 1. The assessment was arranged in randomized complete block design with the split-split plot arrangement (plot size of 1.5 × 3.5 m) keeping P in the main plots, Sulphur sources in sub plots and the levels of S in the sub-sub plots. Treatments were eighteen having diverse combinations of P (0, 50 and 100 kg ha^{-1}) and the S rates (0, 20and 40 kg ha^{-1}) from the two S sources (gypsum and ammonium sulphate). The starter dosage (26 kg ha^{-1}) of N was practiced in the form of urea. Though in the S treatments, urea dosage was accustomed consequently after taking into the deliberation the addition of N from ammonium sulphate (AS). Phosphorus was used in the form of triple super phosphate (TSP). All the treatments were repeated three times. At row to row distance of 30 cm chickpea crop was sown. All the fertilizers were practiced as blanked dose. No supplemental irrigation was applied because crop was grown under rainfed conditions. Total rainfall during cropping period (October to March) was 386 and 91 mm during crop growing period 2014-2015 and 2015-2016.

At the physiological maturity, crop from each plot was harvested separately from an area of one meter square. The plant samples were dried out and data were documented for yield of seed, straw and dry matter. The quadratic response equation was established to be unsurpassed fit to describe the correlation between x and Y as exposed below:

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

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

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

where b and c are the two constants of the quadratic response function and q is the per unit price of P or S and p is the cost of one unit of the seed yield. The yield at EOD of P or S was work out by via quadratic expression: $Y = a + bx + cx^2$

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 function. The response to economic optimal dosage (REOD) of S was calculated by by means of the expression:

REOD = (Yopt – Ycont)/Xopt where Yopt =Yield calculated at EOD; Ycont = Yield in control plot; Xopt = Economic optimal dosage.

The nutrient interactions (synergistic or antagonistic) were estimated by contrasting the raise in yield (in terms of kg ha^{-1} against control) due to pooled P and Sfertilization, with that of individual applications (Fageria, 2001).

The samples of 100 g from both seed and straw were accumulated from bulk sample, oven dried and ground and examined for P (Ryan et al., 2001) and S content (Verma, 1977). The nutrient uptake was figure out by multiplying the relevant nutrient concentration with the dry matter yield.

The nutrient recovery of P and S fertilizer applied was computed by following expression and articulated on the percentage basis (Craswell, 1987).

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

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

Nutrient $Uptake_c$ = Nutrient uptake in control plot

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

Agronomic efficacy was computed by dividing the enhance in yield against control by quantity of the nutrient applied (Ahmad and Rashid, 2003).

The economics of practiced fertilizer was calculated by the value cost ratio (VCR). The VCR value was work out by following method (Ahmad and Rashid, 2003).

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

Costs of input and output existing in the market during financial year 2015-2016 were taken for explaining for economic analysis (NFDC, 2009).

Data collected for all parameters were subjected to the analysis of variance (ANOVA) via software MSTATC. Mean for treatments were compared by the least significant difference (LSD) test.

IV. RESULTS AND DISCUSSION

4.1 Seed yield

There was significant boost in seed yield of chickpea with the application of P (Table 2). Seed yield improved from 0.85 to 1.09 Mg ha^{-1} (data combined over years) as P rate was amplified from 0 to 100 kg P_2O_5 ha^{-1}. Difference among inferior (50 kg P_2O_5 ha^{-1}) and superior level (100 kg P_2O_5 ha^{-1}) of the P was significant. There was 30% boost in seed yield, which is in accord with conclusions of Hayat and Ali (2010) who accounted 10% augment in seed yield of mung bean due to fertilization of 80 kg P_2O_5 ha^{-1} under comparable climatic circumstances. On the other hand, an enhance upto 75% was stated in seed yield of chickpea due to fertilization of 90 kg P_2O_5 ha^{-1} under irrigated situation (Khan, 2002). This difference may be due to the reality that fertilizer use efficiency and reply to nutrient fertilization is usually little under rainfed environments due to the drought stress (Ahmad and Rashid, 2003).

A tendency comparable to the P was also noticed for S concerning seed yield (Table 2). There was an augment up to 13% in the seed yield of the chickpea due to fertilization of 40 kg S ha^{-1}. Hussain (2010) described 15% raise in seed yield of soybean (*Glycine max*) due to fertilization of 40 kg S ha^{-1} under the rainfed environments. The two S sources (gypsum and AS) diverged from each other in their outcome on seed yield (Table 2), which is divergent to the conclusions of Khalid et al. (2009b) who documented non significant differences among gypsum, AS and single super phosphate in term of seed yield of *Brassica napus*. It was also noted that consequence of fertilization of 40 kg S ha^{-1} in the form of gypsum was statistically comparable to 20 kg S ha^{-1} in the form of AS (Table 6). Appropriateness of both source of S differs according to climatic situations, soil kinds, and crop S rations. For crops needing instant reprieve from S paucity, AS is higher, whereas on coarse textured soils and under immense rainfall situations, gypsum is superior due to dawdling discharge of S (Tiwari and Gupta, 2006). The P and S level interaction was significant for the seed yield when data was combined transversely years (Table 2). The utmost seed yield was transcribed in $P_{100}S_{40}$, which was comparable with $P_{100}S_{20}$ and $P_{50}S_{40}$, whereas the little yield was documented in control plots (Table 5). Escalating rate of S fertilization at similar rate of the P resulted in boost in the seed yield, which can be enlightened by an enhancement in general growth processes of the plant, as a consequence of unbiased deliver of the nutrients.

The reply of chickpea to P and S was quadratic in two years (Table 3). The economic optimal dosage of the P and S ranged among 57 to 59 and 33 to 54 kg ha^{-1} correspondingly. Amount of reply in provisions of b value and response at EOD (kg seed yield kg^{-1} S) was superior for P during first year over second year. This may be due to more encouraging climatic environments particularly rainfall (Table 1).

A relationship of the effects of individual and pooled nutrient fertilization demonstrated that mutual outcome of P and S was higher than individual outcome, both at inferior ($P_{50}S_{20}$) and superior levels ($P_{100}S_{40}$) of nutrient fertilization, when data was combined for both years (Table 4). Therefore, there was affirmative or synergistic relations among the P and S. Related results were noted by Jaggi and Sharma (1999). They noticed that mutual fertilization of P and S at their uppermost rate formed highest yield of the raya (*Brassica juncea*) and there was affirmative considerable relations among the P and S. Paliwal et al. (2009) also illustrated synergistic relation among the P and S up to $P_{60}S_{40}$ using soybean (*Glycine max*) as check crop. Therefore, form of interaction among P and S diverges with soil fertility level, climatic environments, trial crop and rate of nutrientfertilization.

4.2 Agronomic efficacy and nutrient recovery

Agronomic efficacy turn down with augment in nutrient fertilization rate (Table 2). It was superior during first year over second year as a result of enhanced climatic situations. Agronomic efficacy was elevated due to collective fertilization of P and S as contrasted to their solitary application (Table 5). These results are in support with the conclusions of Kumar et al. (2011) who also documented diminution in agronomic efficacy of the nutrients with raise in their fertilization rate.

Inferior rates of the S fertilization resulted in superior nutrient return (Table 6). Joint fertilization of the S and P resulted in augment in the S recovery (Table 5). Utmost and least sulphur recovery was transcribed in $P_{100}S_{20}$ and P_0S_{20}, correspondingly. The sulphur recovery for AS was elevated over gypsum (Table 6) which might be accredited to its elevated solubility ensuing in elevated S accessibility for the plant uptake (Ghosh et al., 2000). In the current work, average S recovery was in the range of 3.0 to 7.0 percent, which is close to the value of 3 percent accounted for chickpea (Tandon, 1991). The sulphur fertilizer recovery is managed by a number of aspects such as primary S grade of soil, rate of the S fertilization and nature of the crop.

Level of N, P and K fertilization can also have an outcome on recovery of applied S, as these have impact on largely crop growth (Hedge and Murthy, 2005). These findings are also in accordance with the results of Khalid (2007) who recorded superior S recovery (29.2%) due to AS application against gypsum (14.4%) at the S application rate of 40 kg ha^{-1}. Lesser S recovery in current work might be due to the reality that S requisite of pulses is inferior over oilseed crops and sulphur recovery of 8-10% has been documented for pulses (Hedge and Murthy, 2005). Moreover, unfavorable environmental circumstances, predominantly during second year of the trial resulted in fewer dry matter construction and eventually stumpy S uptake and the S recovery. Raise in the S recovery due to P fertilization might be allocated to considerable enhancement in dry matter creation (Hedge and Murthy, 2005).

Phosphorus recovery was elevated at inferior level of P fertilization (50 kg P_2O_5 ha^{-1}) against superior one (Table 7). Data combined across years point out that P recovery was greatest in $P_{50}S_{20}$ and lowest in $P_{100}S_{40}$. Phosphorus recovery in range of 3.4 to 5.9 percent was greatly inferior than accounted value of 11 to 26 percent, which might be due to the reality that crop was grown under the rainfed environment (Ahmad and Rashid, 2003).

Fertilizer use efficiency in rainfed regions is relatively lesser than in irrigated farming, because of drought stress at vital growth stages. Phosphorus recovery in range of 1.7 to 13.4 percent has been stated in pot trials using soybean as trial crop (Jin et al., 2006). Though, under field situation in irrigated region of Pakistan, P use efficiency has been documented to be in range of 5.2 to 25.7 percent for the wheat and 3.9 to 21.3 percent for the rice (Rehman, 2004).

4.3 Economic analysis

Value cost ratio is the rate of return on currency exhausted on fertilizers. If VCR is larger than one, the fertilizer use will be cost-effective. A VCR of 2 characterizes a 100 percent return on money spends on fertilizer. For elevated technology, suggested VCR is 2, as it guarantees an excellent net return.

At VCR lesser than two, farmer's margin of return becomes little and there is threat of trailing money if there is deprived administration or bad climate. Due to risk factors, VCR of 2 is measured acceptable. In our work, VCR value was superior for S over P and S sources; superior VCR value was documented for gypsum against AS (Table 8). Between diverse P and S combinations, single application of elevated level of the P resulted in the VCR fewer than 2.

V. CONCLUSION

Fertilization of P and S resulted in considerable raise in seed yield. Interaction among P and S was affirmative at both inferior and superior rate of the nutrient application. Economic analysis depicted that fertilizer combination of $P_{100}S_{40}$ was cost-effective as value cost ratio was upper than 2. Sulphur ought to be incorporated in nutrient management programme in order to acquire utmost yield of the pulses. This will result in augmented fertilizer use efficiency and saving of this valuable and expensive input. Though, further trialing is required to formulate comprehensive suggestions concerning accurate ratio of the P and S.

Authors contribution: Tariq shah collect and analyzed the data, Muhammad numan help in writing manuscript and lab work, Ahmad ali design the experiment.

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TABLES AND FIGURES

Table 1: Location, rainfall and physiochemical properties of experimental site.

Parameter	Unit	Value
Latitude	N	32.5°
Longitude	E	72.4°
Mean annual rainfall (1979-2009)	mm	631
Cropping season (October to March) rainfall during (i) 2014-15 (ii) 2015-16	mm	386 91
Sand	%	70
Silt	%	22
Clay	%	11
Texture	-	Sandy loam
pH	-	7.7
ECe	dSm^{-1}	0.33
Total organic carbon	$mg\ g^{-1}$	3.8
$CaCO_3$	%	5.3
Total N	%	0.03
NO_3-N (AB-DTPA extractable)	$\mu g\ g^{-1}$	11.3
Phosphorus (AB-DTPA extractable)	$\mu g\ g^{-1}$	3.1
Sulphate- Sulphur ($CaCl_2$ extractable)	$\mu g\ g^{-1}$	6.5
Zinc (AB-DTPA extractable)	$\mu g\ g^{-1}$	0.76
Copper (AB-DTPA extractable)	$\mu g\ g^{-1}$	1.22
Iron (AB-DTPA extractable)	$\mu g\ g^{-1}$	7.83
Manganese (AB-DTPA extractable)	$\mu g\ g^{-1}$	2.99

Table 2: Effect of P, S and S sources on seed yield (Mg ha^{-1}) and agronomic efficacy

Treatments	Seed yield (Mg ha^{-1})			Agronomic efficiency		
	2014-2015	2015-2016	Mean	2014-2015	2015-2016	Mean
P levels (kg P_2O_5 ha^{-1})						
0	0.99 c	0.71 c	0.85 c	-	-	-
50	1.29 b	0.82 b	1.06 b	7.6	2.9	5.4
100	1.33 a	0.87 a	1.09 a	4.4	2.0	3.1
Significance level	**	**	**	-	-	-
LSD value	0.02	0.03	0.01	-	-	-
S sources						
Gypsum	1.19	0.79	0.99 b	-	-	-
Ammonium sulphate	1.21	0.81	1.01 a	-	-	-
Significance level	NS	NS	**	-	-	-
S levels (kg S ha^{-1})						
0	1.12 c	0.75 c	0.94 c	-	-	-
20	1.23 b	0.81 b	1.01 b	7.4	4.1	5.8
40	1.26 a	0.84 a	1.05 a	4.8	3.1	3.9
Significance level	**	**	**			
LSD value	0.02	0.02	0.01	-	-	-
F values and significance						
levels of interactions						
P × S sources	4.1 NS	0.9 NS	2.5 NS	-	-	-
P × S levels	11.0 **	0.6 NS	4.2 **	-	-	-
S sources × S levels	3.7 *	1.4 NS	3.9 *	-	-	-
P × S sources × S levels	2.4 NS	0.3 NS	0.8NS	-	-	-

Dissimilar letters in the similar column indicate significant differences between treatments (P≤0.05). The values
communicate to averages of three replicates. NS indicate non significant difference;
* and ** represent significance at P≤0.05 and P≤0.01 levels, respectively.

Table 3: Response equation, economic optimal dosage and seed yield at economic optimal dosage of chickpea as function of phosphorus and sulphur.

Treatments	Response Equation (kg ha^{-1})	R^2	Economic optimal Dose (EOD) (kg ha^{-1})	Yield at EOD (kg ha^{-1})	Response at EOD (kg seed yield kg^{-1} P or S)
		2014-2015			
Phosphorus	$Y = 934 + 8.41X - 0.059X^2$	96	59	1224	5.01
Sulphur	$Y = 934 + 3.66X - 0.027X^2$	68	54	1052	2.24
		2015-2016			
Phosphorus	$Y = 657 + 2.94X - 0.012X^2$	92	57	785	2.26
Sulphur	$Y = 657 + 4.58X - 0.058X^2$	72	33	745	2.70

Table 4: Interaction effect among phosphorus and sulphur application concerning seed yield.

Effect	2014-2015 (kg ha^{-1})	2015-2016 (kg ha^{-1})	Mean (kg ha^{-1})
Increase due to sole P over control:			
- with 50 kg P_2O_5 ha^{-1}	241	99	170
- with 100 kg P_2O_5 ha^{-1}	291	158	224
Increase due to sole S over control:			
- with 20 kg S ha^{-1}	50	57	53
- with 40 kg S ha^{-1}	87	86	86
Increase due to combined P and S:			
- with 50 kg P_2O_5 and 20 kg S ha^{-1}	363	172	267
- with 100 kg P_2O_5 and 40 kg S ha^{-1}	435	233	333
Type of interaction:			
- with 50 kg P_2O_5 and 20 kg S ha^{-1}	synergistic	synergistic	synergistic
- with 100 kg P_2O_5 and 40 kg S ha^{-1}	synergistic	antagonistic	synergistic

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

Treatments	Seed yield (Mg ha^{-1})		Agronomic efficiency			Sulphur recovery (%)		
	2014-2015	Mean	2014-2015	2015-2016	Mean	2014-2015	2015-2016	Mean
P_0S_0	0.94 g	0.80 g	-	-	-	-	-	-
P0S20	0.99 f	0.86 f	3.3	3.8	3.6	1.8	2.4	2.1
P0S40	1.03 e	0.89 e	2.9	2.9	3.0	2.3	2.2	2.2
P50S0	1.18 d	0.97 d	6.1	2.5	4.3	-	-	-
P50S20	1.31 b	1.07 b	6.7	3.2	5.0	7.8	4.0	5.9
P50S40	1.38 a	1.12 a	6.3	3.0	4.7	6.9	3.6	5.3
P100S0	1.23 c	1.03 c	3.7	2.1	2.9	-	-	-
P100S20	1.39 a	1.12 a	4.8	2.2	3.5	9.9	5	7.0
P100S40	1.38 a	1.13 a	4.0	2.2	3.1	4.5	3.5	4.0

Dissimilar letters in the similar column indicate significant differences between treatments (P≤0.05). The values communicate 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 (%)		
	2014-2015	Mean	2014-2015	2015-2016	Mean
Gypsum (kg S ha^{-1})					
0	1.12 d	0.94 d	-	-	-
20	1.21 c	1.00 c	5.2	2.6	3.9
40	1.25 b	1.04 b	3.3	2.5	2.9
Ammonium sulphate (kg S ha^{-1})					
0	1.11 d	0.94 d	-	-	-
20	1.25 b	1.04 b	7.9	4.4	6.1
40	1.26 a	1.06 a	5.8	3.7	4.8

Dissimilar letters in the similar column indicate significant differences between treatments (P≤0.05). The values communicate to averages of three replicates

Table 7: Phosphorus recovery as a function of phosphorus dosages within each sulphur level

Treatments	2014-2015	2015-2016	Mean
P levels:			
0	-	-	-
50	7.97	2.76	5.34
10	5.16	2.62	3.88
P × S levels interaction:			
P_oS_o	-	-	-
P0S20	6.25	2.91	4.59
P0S40	4.59	2.53	3.56
P50S0	-	-	-
P50S20	8.60	3.10	5.85
P50S40	6.57	3.13	4.85
P100S0	-	-	-
P100S20	8.94	2.30	5.62
P100S40	4.31	2.22	3.27

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

Treatments	2014-2015	2015-2016	Mean
Phosphorus levels (kg P_2O_5 ha^{-1}):			
0	-	-	-
50	4.76	1.76	3.26
100	2.72	1.20	1.96
Gypsum (kg S ha^{-1}):			
0	-	-	-
20	14.34	7.18	10.84
40	10.18	6.51	8.34
Ammonium sulphate (kg S ha^{-1}):			
0	-	-	-
20	6.92	3.94	5.38
40	4.24	2.70	3.44
P × S levels interaction:			
P_oS_o	-	-	-
P0S20	3.89	4.54	4.21
P0S40	3.44	3.44	3.44
P50S0	3.80	1.56	2.68
P50S20	4.77	2.27	3.52
P50S40	4.92	2.34	3.63
P100S0	2.29	1.25	1.77
P100S20	3.19	1.48	2.33
P100S40	2.86	1.55	2.20

*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 whereas that of chickpea as Rs. 1600 per 40 kg.