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Research Paper

Optimizing sulphur application in sunflower (*Helianthus annuus*) under irrigated semi-arid tropical conditions

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ABSTRACT

A field experiment comprising varying levels of sulphur (0, 20 and 40 kg S/ha) applied through different sources (ammonium sulphate, single super phosphate, gypsum and elemental sulphur) was conducted on loamy sand soil at Ludhiana, Punjab during spring seasons of 2008 and 2009 to identify the optimum dose and better source of sulphur for higher sunflower productivity. Significant improvement in seed yield of sunflower was observed with each incremental dose of sulphur up to 40 kg S/ha with 6.9–9.0% yield superiority over control. The application of graded doses of sulphur at the rates of 20 and 40 kg S/ha through gypsum increased the seed yield over control by 8.6 and 10.7%, respectively, whereas the corresponding increases were 8.5 and 10.4% for ammonium sulphate, 5.4 and 7.3% for single super phosphate and 4.9 and 7.5% for elemental sulphur at the respective levels of sulphur nutrition. Highest seed yield (2.66 t/ha), oil content (42.9%), net returns (₹ 46.3 × 10^3/ha) and B:C ratio (4.08) was recorded with application of 40 kg S/ha applied through gypsum. Positive and highly significant correlation was observed between seed yield and head diameter (r=0.977**), dry matter accumulation (r=0.935), seed weight (r=0.810**). Oil content in the seed recorded a positive and highly significant relationship with uptake of N (r=0.984**), P (r=0.993**) and S (r=0.978**), signifying the importance of balanced nutrition in improving the oil content. Almost similar seed yield can be obtained with economic optimum dose of sulphur, indicating the saving of S ranging from 0.4 to 6.6 kg/ha depending upon the source.

Key words: Dose optimization, Growth dynamics, Nutrient uptake, Sources of sulphur, Sunflower

Inspite of cultivation of number of oilseed crops, country meets 50% of its domestic requirements through import. One of the main reasons for this inadequate carrying capacity is their low productivity and stagnation or decline in area under principal oilseed crops such as, rapeseed-mustard and groundnut. With burgeoning population, improved living standard and purchasing power of the people, the demand of vegetable oil in the country is increasing at the rate of about 4–6% (Agarwal, 2007). Therefore, there is urgent need to improve the productivity of oilseed crops to bridge up the current demand-supply gap.

Sunflower is second most important oilseed crop after groundnut in the southern and western parts of the country and has also been cultivated on significant area in north India since last two and a half decades. It holds great promise due to its short duration, high per day productivity, photo-insensitivity, wider acclimatization and polyunsaturated fatty acids rich edible oil. Favourable fatty acid composition, colourless and odourless nature of sunflower oil makes it one of the best choices for blending with other edible oils. Cultivation of sunflower during spring season in north India not only promises two to three times higher productivity owing to favourable agro-climatic conditions, low incidence of pests and abundant honey bees activity, which aids to seed setting of this cross pollinated crop but also fits well in the multiple cropping systems. Attempts are, therefore, needed for its horizontal and vertical intensification to overcome the chronic shortage of edible oils in the country.

Sustainable production requires efficient use of inputs including adequate and balanced fertilization. Sulphur (S) is considered as the fourth most important essential element after N, P and K for crop production and is actively involved in plant growth, seed yield, oil and protein synthesis as well as improved quality of produce owing to its role in enzymatic and metabolic processes (Roche *et al.*, 2004; Hussain *et al.*, 2011). In general, S requirement of oilseed crops is higher than those of cereal crops (Scherer,

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2001; Hegde and Sudhakar Babu, 2009) but its application as a fertilizer or as a constituent of other fertilizers is generally overlooked resulting in widespread deficiency of this element (Irwin *et al.*, 2002; Scherer, 2001). The native plant available S rarely exceeds 10–20 kg/ha and mostly soils are categorized as low to medium in S availability (Takkar, 1988). The response of sunflower to S fertilization is guided by soil type, cropping systems followed and prevailing weather conditions. Several studies have also established the synergistic and interactive response of S nutrition with N and P application on enzymatic activities, protein synthesis and nodulation activities (Barney and Bush, 1985; Brunold and Suter, 1984; Deshbhratar *et al.*, 2010). Keeping in view the important role of S in oilseed crops including sunflower, increasing use of S free fertilizers and its increasing deficiency particularly under intensive cropping systems, an attempt was made to optimize S requirements and to identify best source of S supply for sunflower crop under Punjab conditions, where the commercial cultivation is limited to spring season.

MATERIALS AND METHODS

A field experiment was carried out during spring seasons of 2008 and 2009 at Punjab Agricultural University, Ludhiana (30º56' N, 75º52' E, 247 meters above mean sea level). The soil of experimental site (0–15 and 15–30 cm depth) was loamy sand in texture (77.2 ± 2.7% sand; 14.6 ± 1.5% silt; 12.6 ± 1.2% clay), slightly alkaline in nature (pH 7.9 ± 0.5), free from salts (0.20 ± 0.1 dS/m), low in organic carbon (0.19 ± 0.1%), available nitrogen (109 ± 3.5 kg/ha $KMnO_4$-N) and available sulphur (7. 2 ± 2.5 ppm $CaCl_2$-S), medium in available phosphorus (11.21 ± 0.65 kg/ha Olsen's P) and potassium (155 ± 4.5 kg/ha NH_4OAC-K). Treatment consisting four sources of S *viz.*, ammonium sulphate (AS), single super phosphate (SSP), gypsum (Gyp) and elemental sulphur (ES) were evaluated at two levels (20 and 40 kg S/ha) along with control in three times randomized block design. Sunflower hybrid 'PSH 569' was planted in the first fortnight of February by dibbling three seeds per hill in seven-row plots, 5.1 m long with spacing of 0.6 m between rows and 0.3 m within rows each year. After complete germination, one plant per hill was retained by thinning extra plants at the three-four leaf stage. Crops was uniformly fertilized with 60 kg N and 30 kg P_2O_5 per ha with urea (46% N) and di-ammonium phosphate (18% N, 46% P_2O_5) respectively, the doses of which were adjusted taking into consideration the contribution of N and P from ammonium sulphate and single super phosphate. Muriate of potash (30 kg K_2O/ha) was also uniformly applied. Half dose of N and full dose of P, K and S as per treatments were drilled at the time of sowing, while remaining half dose of N was top dressed at 30–35 days after planting of sunflower after application of first irrigation. At harvest, five representative plants from each treatment plot were randomly selected for recording observations on growth (plant height, stem girth) dynamics and yield determinants (head diameter, 100-seed weight). At maturity, head samples for yield were harvested from the center rows of each plot leaving one row on either side of treatment plot, dried and threshed manually to determine the seed yield, which was then expressed in t/ha.

Oil content in the whole seed was determined by employing non-destructive method of oil estimation using nuclear magnetic resonance spectroscope-Newport Analyzer Model MK 111A. For plant (N and P) analysis, 0.5 g plant samples were digested in di-acid mixture of H_2SO_4 and $HClO_4$ and N content was estimated using standard procedures by modified Kjeldhal method, while P concentration by vanadomolybedophosphoric yellow colour method. Sulphur concentration in plant samples was determined turbidimetrically after digesting the samples in di-acid mixture of HNO_3 and $HClO_4$. The data thus obtained were analyzed statistically using analysis of variance technique for various parameters at 5% level of significance.

The economics of different treatments were also worked out by using the prevailing market prices of the produce and the inputs used. Optimum dose for each source of S was worked out by employing quadratic equation $Y = a + bS - cS^2$ (where, Y= seed yield in kg/ha, S = the dosage of the S applied in kg/ha and a, b and c are the constants), which were differentiated to $dY/dS = 0 + b - 2cS$ and the $S_{Physical\ optimum} = b/2c$ and $S_{Economic\ optimum} = [b - (PS/PY)]/2c$ were calculated (where PS is unit price of S depending on the source and PY is unit price of sunflower seed).

RESULTS AND DISCUSSION

Effect of growing season

The overall crop yield in the year 2009 was significantly higher as compared to 2008 (Table 1). Seed weight is one of the major determinants of yield in sunflower and in the present study, it contributed significantly to improved productivity in 2009 compared to previous year. Favourable weather conditions might have contributed to more assimilation of metabolites and subsequently paved way for their more efficient translocation from vegetative plant parts to reproductive organs contributing to significantly higher 100-seed weight (Table 1). Such significant relationships between seasonal variations on plant growth, yield components and final harvest have earlier been reported by Chapman and De La Vega (2002) and Hassan *et al;* (2007). Similar trend was discerned for oil content and oil yield.

Sulphur levels

Each incremental dose of S resulted in linear and significant increase in seed yield up to 40 kg S/ha (Table 1). The highest seed yield (2.623 t/ha) obtained with application of 40 kg S/ha was 1.9% higher over 20 kg S/ha and 9.0% higher over that obtained without S application (2.406 t/ha). Similarly, application of 20 kg S/ha resulted in 6.9% higher seed yield over its yield obtained without S application. Sulphur application resulted in increased plant height and stem girth as well as larger head diameter and higher 100-seed weight (Table 1). The study reveals higher uptake of nutrients with increasing S application (Table 3). Similar positive responses of S on plant growth parameters, yield attributes and seed yield have also been reported by Sirohi and Abrol (1991) and Ozer *et al.*, (2004).

S application though resulted in marginal improvement in seed oil content (Table 1) but showed significant enhancement in oil yield (Table 2). The oil yield increased by 8.0% with S application of 20 kg S/ha and by 10.4% with 40 kg S/ha in comparison to without S application. Improvement in oil content might be attributed to better fatty acid synthesis (conversion of acetyl Co-A to molonyl Co-A) resulting from increased activity of thiokinase enzyme which itself depends on S supply. In the absence of S, carbohydrates are not fully utilized for the formation of oil. Beneficial role of S in increasing the oil content in matured kernels has also been reported by Legha and Giri (1999). Increased seed yield as well as oil content might have culminated towards increased oil yield due to S application.

Consistent and significant improvement in N, P and S content and their uptake in both seed and straw (except content) was discerned with increasing doses of S (Table 3). Application of 20 kg S/ha increased the N, P and S content by 0.12, 0.09 and 0.07% in seed and 0.06, 0.01 and 0.04% in straw, respectively over without application of S. Further increase in S to 40 kg/ha resulted in non-conspicuous increase in nutrient content. Application of 40 kg S/ha resulted in 14.2 and 19.0% higher N uptake,

Table 1. Effect of dose and source of sulphur on the growth, yield attributing characters and yield of sunflower

Treatment		Seed yield (t/ha)	Plant height (cm)	Stem girth (cm)	Head diameter (cm)	100-seed weight (g)	Oil content (%)	Oil yield (t/ha)
Years (Y)	2008	2.344	148.1	7.56	17.4	5.34	43.6	1.023
	2009	2.724	152.3	6.43	16.1	7.18	41.3	1.124
	SEm±	0.012	0.7	0.04	0.03	0.11	0.06	0.006
	CD (P=0.05)	0.036	2.0	0.11	0.09	0.31	0.16	0.018
Sulphur rate (R)	Control	2.406	148.9	6.95	16.5	6.18	42.1	1.011
	20 kg S/ha	2.573	150.4	7.00	16.8	6.28	42.5	1.092
	40 kg S/ha	2.623	151.3	7.03	17.0	6.30	42.7	1.116
	SEm±	0.016	0.8	0.03	0.03	0.02	0.02	0.008
	CD (P=0.05)	0.047	NS	NS	0.08	0.06	NS	22.1
Sulphur source (S)	Ammonium sulphate	2.559	150.9	6.96	16.8	6.25	42.5	1.087
	Single super phosphate	2.509	149.7	6.94	16.7	6.26	42.4	1.061
	Gypsum	2.561	148.9	6.98	16.8	6.29	42.6	1.089
	Elemental sulphur	2.507	151.3	7.08	16.8	6.23	42.2	1.056
	SEm±	0.001	0.7	0.04	0.02	0.03	0.02	0.009
	CD (P=0.05)	0.003	NS	NS	NS	NS	NS	0.026

Table 2. Interactive effect of dose and source of sulphur on the seed yield of sunflower

Sulphur sources	Seed yield (t/ha)					
	2008		2009		Mean of 2 years	
	20 kg S/ha	40 kg S/ha	20 kg S/ha	40 kg S/ha	20 kg S/ha	40 kg S/ha
Ammonium sulphate	2.448 (1.074)	2.492 (1.094)	2.776 (1.154)	2.824 (1.174)	2.612 (1.114)	2.658 (1.134)
Single super phosphate	2.357 (1.028)	2.385 (1.041)	2.718 (1.122)	2.779 (1.153)	2.538 (1.075)	2.582 (1.097)
Gypsum	2.445 (1.080)	2.495 (1.108)	2.783 (1.152)	2.833 (1.173)	2.614 (1.116)	2.664 (1.141)
Elemental sulphur	2.308 (1.001)	2.347 (1.021)	2.744 (1.127)	2.829 (1.167)	2.526 (1.084)	2.588 (1.094)
Control	2.221 (0.958)		2.601 (1.040)		2.407 (0.999)	
SEm±	0.057		0.032		0.023	
CD (P=0.05)	0.171		0.098		0.066	

Figures in parentheses indicate the oil yield in t/ha

26.2 and 17.1% higher P uptake and 44.4 and 34.7% higher S uptake in seed and straw, respectively in comparison to no S application. Similarly, application of 20 kg S/ha increased the uptake in seed and straw to the tune of 10.8 and 14.8% of N, 20.4 and 13.1% of P and 37.9 and 27.5% of K uptake over the treatment of without S application. This could be ascribed to synergistic effect of S in increasing the nitrate reductase activity (Dev and Kumar, 1982) and mobilizing the soil P (Choudhary *et al;* 1991) for higher plant nutrient uptake. Sulphur application resulted in better returns as compared to without S application (Table 5). The net monetary benefit of ₹3572/- and 4396/- with incremental cost benefit ratio (ICBR) of 13.3 and 7.3 per rupee invested was obtained with application of 20 and 40 kg S/ha, respectively in comparison to without S application.

Sources of sulphur

Sulphur application through gypsum resulted in significantly higher seed (2.56 t/ha) and oil (1.09 t/ha) yield over its application through other test sources except ammonium sulphate (Table 1). S application through gypsum maintained its superiority in improving contents and uptake of nutrients (N, P and S) in both seed and straw over other sources of S (Table 3). Elemental S was found to be the least effective one among the S sources in influencing the yield attributes, yield, nutrient content and their uptake. Numerically higher values of growth characters as well as yield determinants (Table 1) could be the possible reason for better uptake (Table 3) and statistically higher seed yield both under gypsum and ammonium sulphate as S source. Contrary to this, elemental S is regarded as slow release fertilizer, which first requires to be oxidized to sulphate S by soil micro-organisms before being taken up by the plants. Duhoon *et al*. (2005) also reported relatively less effectiveness of elemental S as S source in sesame.

Interaction between levels and sources of sulphur

Among the four sources of S, gypsum and ammonium sulphate being at par uphold their superiority with rest of the S sources at the corresponding levels of S application. Highest seed yield of 2.66 t/ha was recorded with application of 40 kg S/ha through gypsum and ammonium sulphate maintaining yield superiority by 10.7% over control. S application through gypsum (20 and 40 kg S/ha) though found to be at par with ammonium sulphate but it culminated in 3.0 and 3.2% higher seed yield than single super phospahe and 3.5 and 2.9% higher seed yield than elemental S. Linear response in seed yield of sunflower was observed with the increasing levels of S under all the sources of S supply. First incremental dose of S (0 to 20 kg S/ha) improved seed yield to the tune of 5.0% (with elemental S)

Table 3. Effect of dose and source of sulphur on the nutrient (N, P and S) concentration and their uptake in seed and straw of sunflower

Treatment		Nutrient content (%)						Nutrient uptake (kg/ha)						Total uptake (kg/ha)		
		Seed			Straw			Seed			Straw					
		N	P	S	N	P	S	N	P	S	N	P	S	N	P	S
Sulphur rate (R)	Control	3.41	0.74	0.25	0.51	0.08	0.15	81.95	17.83	5.99	28.30	4.49	8.47	110.3	22.3	14.5
	20 kg S/ha	3.53	0.83	0.32	0.57	0.09	0.19	90.86	21.47	8.26	32.33	5.08	10.80	123.2	26.6	19.1
	40 kg S/ha	3.57	0.86	0.33	0.59	0.09	0.20	93.60	22.51	8.65	33.68	5.26	11.41	127.3	27.8	20.1
	SEm±	0.029	0.018	0.013	0.013	0.008	0.011	0.64	0.44	0.30	0.57	0.14	0.31	1.58	0.58	0.96
	CD (P=0.05)	0.086	0.052	0.039	0.038	NS	0.028	1.92	1.31	0.88	1.76	0.43	0.89	4.66	1.74	2.86
Sulphur source (S)	Ammonium sulphate	3.52	0.82	0.31	0.56	0.09	0.19	90.18	20.98	7.87	31.68	5.07	10.51	121.9	26.1	18.4
	Single super phosphate	3.50	0.81	0.30	0.55	0.09	0.18	87.80	20.31	7.57	30.73	4.77	10.00	118.5	25.1	17.6
	Gypsum	3.53	0.83	0.31	0.59	0.09	0.19	90.59	21.23	7.94	33.40	5.27	10.93	124.0	26.5	18.9
	Elemental sulphur	3.46	0.79	0.28	0.53	0.08	0.17	86.64	19.88	7.14	29.94	4.66	9.47	116.6	24.5	16.6
	SEm±	0.011	0.021	0.006	0.016	0.005	0.013	0.48	0.35	0.32	0.95	0.10	0.34	0.84	0.32	0.20
	CD (P=0.05)	0.032	NS	0.017	0.046	NS	NS	1.43	1.02	NS	2.82	0.28	1.01	2.49	0.94	0.58

to 8.7% (with gypsum) whereas, further increase in S (20 to 40 kg/ha) application enhanced seed yield by 1.8% (with ammonium sulphate) to 2.5% (with elemental S). The interactive effect of dose and source of S supply revealed that highest increase in seed yield (8.6 and 10.5%) over control accrued with the application of ammonium sulphate at the rate of 20 and 40 kg/ha, respectively (Table 2). The corresponding increases with gypsum, single super phosphate and elemental sulphur were 8.7 and 10.7%, 5.5 and 7.3% and 5.0 and 7.6%, respectively (Table 2). Increase in oil yield with application of 20 and 40 kg S/ha was of the order of 10.4 and 12.8% with gypsum, 10.2 and 12.2% for ammonium sulphate, 6.3 and 8.5% for single super phosphate, and 5.2 and 8.2% for elemental S as compared to no S application.

The highest total N (133.3 kg/ha), P (29.1 kg/ha) and S (21.6 kg/ha) uptake (Table 4), net returns (₹46.3 × 10^3/ha) with benefit: cost ratio of 4.08 was obtained with application of 40 kg S/ha through gypsum (Table 6).

Correlation studies

Linear, quadratic, square root and mitscherlich models were fitted to find out relationship between yield and fertilizer dose and the quadratic model depicted the best fit. Positive and highly significant correlation (Table 7) of seed yield with dry matter accumulation (r = 0.935**), head diameter (r = 0.977**) with seed weight (r = 0.810**) indicated accumulation of metabolites in adequate amount during vegetative growth phase and their efficient translocation to sink during reproductive growth phase for improving yield attributes, which ultimately contributed to improved seed yield. Dry matter accumulation

Table 4. Interactive effect of dose and source of sulphur on the nutrient (N, P and S) uptake of sunflower

Sulphur sources	Total uptake (kg/ha)					
	N uptake		P uptake		S uptake	
	20 kg S/ha	40 kg S/ha	20 kg S/ha	40 kg S/ha	20 kg S/ha	40 kg S/ha
Ammonium sulphate	125.9	129.5	27.5	28.4	20.0	20.7
Single super phosphate	120.7	124.7	25.9	27.1	18.7	19.6
Gypsum	128.5	133.3	28.1	29.1	20.6	21.6
Elemental sulphur	117.8	121.7	24.8	26.6	17.0	18.5
Control	110.3		22.3		14.5	
SEm±	1.48		0.46		0.61	
CD (P=0.05)	4.42		1.36		1.81	

Table 5. Effect of dose and source of sulphur on the economic returns in sunflower

Treatment		Cost of cultivation (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit : cost ratio
Sulphur rate (R)	Control	14.9	40.5	3.72
	20 kg S/ha	15.2	44.3	3.93
	40 kg S/ha	15.5	44.9	3.90
	SEm±	0.16	0.08	0.05
	CD (P=0.05)	0.48	2.3	0.14
Sulphur source (S)	Ammonium sulphate	15.3	43.6	3.86
	Single super phosphate	15.1	42.9	3.84
	Gypsum	14.9	44.0	3.94
	Elemental sulphur	15.3	42.2	3.77
	SEm±	0.07	0.28	0.02
	CD (P=0.05)	0.20	0.82	0.06

Table 6. Economics of different treatments as influenced by doses and sources of sulphur fertilization in sunflower

Sulphur sources	Cost of cultivation (× 10^3₹/ha)		Net returns (× 10^3₹/ha)		Benefit: cost ratio	
	20 kg S/ha	40 kg S/ha	20 kg S/ha	40 kg S/ha	20 kg S/ha	40 kg S/ha
Ammonium sulphate	15.3	15.6	44.9	45.5	3.94	3.91
Single super phosphate	15.1	15.5	44.4	43.9	3.95	3.83
Gypsum	15.0	15.0	45.2	46.3	4.02	4.08
Elemental sulphur	15.3	15.7	42.8	43.8	3.79	3.79
Control	14.9		40.5		3.72	

Table 7. Correlation matrix showing interrelationships between plant growth parameters, yield attributing characters, seed yield and nutrients content and their uptake

Parameters	Plant height	Stem girth	Head diameter	Seed weight	Oil content	Oil yield	DMA	N content	P content	S content	N uptake	P uptake	S uptake	Seed yield
Plant height														
Stem girth	0.638^{NS}													
Head diameter	0.429^{NS}	0.354^{NS}												
Seed weight	-0.095^{NS}	-0.193^{NS}	0.459^{NS}											
Oil content	-0.167^{NS}	-0.328^{NS}	0.444^{NS}	0.883**										
Oil yield	0.186^{NS}	-0.041^{NS}	0.650^{NS}	0.828**	0.923**									
DMA	0.071^{NS}	0.036^{NS}	0.666^{NS}	0.842**	0.871**	0.939**								
N content	-0.006^{NS}	-0.197^{NS}	0.582^{NS}	0.855**	0.972**	0.979**	0.922**							
P content	0.144^{NS}	-0.084^{NS}	0.618^{NS}	0.843**	0.939**	0.979**	0.896**	0.972**						
S content	0.020^{NS}	-0.234^{NS}	0.534^{NS}	0.848**	0.970**	0.972**	0.889**	0.992**	0.982**					
N uptake	0.018^{NS}	-0.143^{NS}	0.606^{NS}	0.867**	0.962**	0.984**	0.954**	0.995**	0.967**	0.981**				
P uptake	0.099^{NS}	-0.089^{NS}	0.609^{NS}	0.862**	0.952**	0.993**	0.942**	0.989**	0.989**	0.986**	0.992**			
S uptake	0.022^{NS}	-0.206^{NS}	0.570^{NS}	0.870**	0.971**	0.978**	0.914**	0.996**	0.984**	0.998**	0.990**	0.992**		
Seed yield	0.252^{NS}	0.021^{NS}	0.977*	0.810**	0.891**	0.997**	0.935**	0.963**	0.973**	0.956**	0.971**	0.985**	0.964**	

*Significant at P=0.05, **Significant at P=0.01

Table 8. Response function, optimum dose and yield under different sources of sulphur in sunflower

Particular	Ammonium sulphate		Single super phosphate		Gypsum		Elemental sulphur	
	$S_{Econ\ Opt}$	$S_{Phy\ Opt}$	$S_{Econ\ Opt}$	$S_{Phy\ Opt}$	$S_{Econ\ Opt}$	$S_{Phy\ Opt}$	$S_{Econ\ Opt}$	$S_{Phy\ Opt}$
Response equation	$Y = 2406.5 + 14.263x - 0.199x^2$		$Y = 2406.5 + 8.713x - 0.108x^2$		$Y = 2406.5 + 14.312x - 0.197x^2$		$Y=2406.5 + 7.413x - 0.072x^2$	
S dose (kg/ha)	32.3	35.8	34.1	40.3	35.9	36.3	44.9	51.5
Grain yield (t/ha)	2.659	2.662	2.578	2.582	2.667	2.667	2.594	2.598

$S_{Econ\ Opt}$ = Economic optimum dose of sulphur, $S_{Phy\ Opt}$ = Physical optimum dose of sulphur

was highly significantly and positively associated with N (r = 0.954**), P (r = 0.942**) and S (r = 0.914**) uptake, elucidating the inter dependence of these elements on each other. Strong correlation discerned between S supply and N (r = 0.990**) and P (r = 0.992**) uptake, implied the beneficial role of S application in improving the uptake of other plant nutrients. Highly significant and positive relationship of seed oil content with uptake of N (r = 0.984**), P (r = 0.993**) and S (r = 0.978**) signifies the importance of balanced nutrition in improving the seed oil content.

Dose optimization

The polynomial relationship between dose of S and seed yield of sunflower was significant, which indicated that yield increased with increase in S dose. The $S_{Economic\ optimum}$ ranged from 32.3 to 44.9 kg/ha depending upon the source of S and was comparatively higher than the $S_{Physical\ optimum}$ for all the sources of S (Table 8). Seed yield obtained with $S_{Physical\ optimum}$ and $S_{Economic\ optimum}$ was almost identical under all the sources of S. The present study reveals saving of S ranging from 0.4 to 6.6 kg/ha for different sources of S.

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