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Effect of different sources and levels of sulphur on yield, sulphur uptake and quality of rainfed sunflower (*Helianthus annus* L.)

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Abstract
A field experiment conducted on sunflower during *kharif* of 2016 in vertisol under rainfed condition at Main Agriculture Research Station, Raichur revealed that Among the different sources of sulphur, significantly higher grain and stalk yield (1648 and 2504.3 kg ha^{-1}), oil content and oil yield (37.84% and 624.84 kg ha^{-1}), protein content and protein yield (16.22% and 268.68 kg ha^{-1}), sulphur availability and total sulphur uptake in soil after harvest of the crop (16.35 kg ha^{-1} and 15.56 kg ha^{-1}) was recorded with ammonium sulphate compared to gypsum. Among the different levels of sulphur, significantly higher grain and stalk yield (1719.83 and 2558.75 kg ha^{-1}), oil content and oil yield (38.23% and 657.75 kg ha^{-1}), protein content and protein yield (17.08% and 294.33 kg ha^{-1}), sulphur availability and total sulphur uptake in soil after harvest of the crop (17.55 kg ha^{-1} and 18.07 kg ha^{-1}) was recorded with 45 g S ha^{-1} fallowed by 30 kg S ha^{-1} and 15 kg S ha^{-1}.

Keywords: Sunflower, sulphur, oil content, protein content, sources, levels

Introduction
Sunflower (*Helianthus annuus* L.) holds great promise as an oilseed crop because of its short duration, photo-in-sensitive and wide adoptability to different agro climatic regions and soil types. Major sunflower area is concentrated in the northern districts of Bijapur, Gulbarga, Raichur and Dharwad, which accounts for nearly 85 per cent of total State acreage. In rainfed production systems, the deficiency of nutrients spread is increasing due to little amounts of organic manures used, poor recycling of crop residues and insufficient use of sulphur containing fertilizers. The deficiency of sulphur in soils and plants are being reported by several parts of the country and also from Karnataka state. In recent years, the survey conducted by Girishchander *et al*. (2008) indicated that most of the farmers fields in Karnataka are deficient in sulphur (59-80%). The yield of oilseed crops, especially sunflower, is severely affected due to sulphur deficiency. The most commonly encountered problem is the occurrence of poor seed set and unfilled seed resulting in low oil recovery percentages. The essentiality of sulphur in the biosynthesis of oil in sunflower has been proved by Bhagat *et al.*, 2005 [2]. Average sulphur uptake per tonne of economic yield of sunflower in India is in the range of 6.2 to 11.7 kg. Sulphur is considered as quality nutrient as its application not only influences crop yield but also improves crop quality, protein metabolism, oil synthesis and formation of amino acids. It is a constituent of three amino acids *viz.* Methionin (21% S), Cysteine (26% S) and Cystine (27% S) which are the building blocks of protein. It is also involved in the formation of chlorophyll, glucosides and glucosinolates (mustard oils), activation of enzymes and sulphydryl (SH) linkages that are the sources of pungency in onion, oils etc. Sulphur is applied to soil through various sources like ammonium sulphate (24% S), SSP (12% S), gypsum (13-18% S), elemental sulphur (100% S), pyrites (24% S), zinc sulphate (11% S) and magnesium sulphate (14% S) *etc*. Sources of sulphur vary depending on the soil type. Among these sources, gypsum, SSP and ammonium sulphate are cheaper. Most of the black soils in Northern Karnataka with arid climate are rich in free calcium and the sulphur nutrient element is render less available to the growing plant. The quantity applied is very less and is inadequate for improved varieties or hybrids. Hence, the field study was conducted to investigate the effect of different sources and levels of sulphur on yield, quality, sulphur uptake and availability in sunflower under rainfed conditions of Raichur, Karnataka.

Material and methods
The experiment was conducted at Main Agriculture Research Station, Raichur during *kharif* 2016-17. The field experiment was laid out in factorial RBD design and replicated thrice with

twelve treatments comprised of 3 sulphur levels, *i.e*. 15, 30 and 45 kg S ha^{-1} supplied through 4 sources, *i.e*. elemental sulphur, gypsum, ammonium sulphate and SSP was tested on sunflower hybrid 'KBSH-44'. The seeds were sown on 16-08-2016 by hand dibbling at each hill with a spacing of 60 cm x 30 cm. A uniform dose of 90 kg P_2O_5 and 60 kg K_2O ha^{-1} was applied through diammonium phosphate (DAP) and muriate of potash (MOP) as basal dose to all the plots at the time of sowing. Nitrogen (90 kg ha^{-1}) was applied through urea, half at sowing and the remaining half as topdressing at 30 DAS to all the treatments. Sulphur was applied as per the treatments in the form of elemental sulphur, gypsum, ammonium sulphate and SSP at the time of sowing. The levels of nitrogen and phosphorus were adjusted when sulphur was applied through ammonium sulphate and SSP

All the recommended cultural practices and required suitable plant protection measures were adopted to raise a good crop. The crop was considered mature, when the back of heads turned to lemon yellow. The heads of border rows were harvested first and treated as bulk. Later the heads of crop from net plot was harvested. The heads were sun dried, shelled with hand and the grains were separated. Later grains were sun dried to a moisture content of 14 per cent, cleaned and weighed separately for each plot. The stover yield was recorded after sun drying the plant to a constant weight.

Sulphur uptake in different parts of sunflower crop at harvest stage was calculated by the fallowing formula.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{[\text{\% of nutrient concentration x biomass (kg ha}^{-1}\text{)}]}{100}$$

Different quality parameters *viz*, protein content, protein yield, oil content and oil yield were calculated by fallowing formulas.

Oil content (%)

Oil content in the grains of each treatment was estimated by Nuclear Magnetic Resonance (NMR) method as suggested by Tiwari *et al.*, (1974) [3] and expressed as percentage.

Oil yield (kg ha^{-1})

Oil yield in the grains of each treatment was calculated by multiplying oil content with grain yield.

$$\text{Oil yield (kg ha}^{-1}\text{)} = \frac{\text{Grain yield x oil content}}{100}$$

Protein content (%)

The crude protein content in sunflower grains was computed by multiplying percent nitrogen content of grain by the factor 6.25.

Results and discussion

Yield

The outcome of the investigation presented in Table 1 revealed that application of different sources and levels of sulphur significantly increased grain and stalk yield at harvest stage of sunflower. Among the sulphur sources, application of ammonium sulphate (S_3) recorded significantly higher grain and stalk yield (1648.0 and 2504.29 kg ha^{-1}) compared to elemental sulphur (S_1) and however, grain yield was on par with SSP and gypsum whereas, stalk yield was on par with SSP. The higher grain and stalk yield through ammonium sulphate might be due to better availability of sulphur as compared to other sources (SSP, gypsum and elemental sulphur) as it is more soluble and release the sulphate ions immediately into soil solution for absorption by the crop to produce better yields. The next best source of sulphur in terms of above parameter found to be SSP. Superiority of ammonium sulphate over other sources has been reported by Tomar (2012) [4] in different oilseed crops. The variation in grain and stalk yield due to levels of sulphur were found significant at harvest stage of the crop. The increase in levels of sulphur exhibited the increment in grain and stalk yield of sunflower up to 45 kg S ha^{-1}. Application of 45 kg S ha^{-1} registered significantly higher grain and stalk yield (1719.83 kg ha^{-1} and 2558.75 kg ha^{-1}) and showed statistical superiority over remaining sulphur levels of 15 kg S ha^{-1} and 30 kg S ha^{-1}. The favourable effect of sulphur fertilization at higher levels on yield might be due to balanced nutritional environment, efficient and greater partitioning of metabolites and adequate translocation of nutrients towards reproductive site. The increase in grain and stalk yield might be due to stimulatory effect of applied sulphur on the synthesis of protein, which in turn might have accelerated photosynthesis and improved most of the yield contributing characters which resulted in significantly higher grain and stalk yield (Tulasi *et al*. 2014) [5].

Quality parameters

The quality determining components such as oil content, oil yield, protein content and protein yield were significantly influenced by the sources and levels of sulphur (Table 2). Different sulphur sources showed significant influence on oil content and oil yield of sunflower. Among the sources, significantly higher oil content (37.84%) and oil yield (624.84 kg ha^{-1}) was recorded with the application of ammonium sulphate (S_3) compared to gypsum (S_2) and elemental sulphur (S_1) and however, it was on par with SSP (36.23%) and (593.35 kg ha^{-1}). The higher oil content and yield with ammonium sulphate might be due to better availability of sulphur as compared to other sources (SSP, gypsum and elemental sulphur). Patel *et al*. (2002) [6] also found similar findings in safflower.

Different levels of sulphur showed significant influence on oil content and oil yield of sunflower. The treatment receiving 45 kg S ha^{-1} (L_3) resulted in significantly higher oil content (38.23%) and oil yield (657.75 kg ha^{-1}). This was significantly superior over 15 kg S ha^{-1} (33.01%) and (489.52 kg ha^{-1}) and however it was on par with 30 kg S ha^{-1} (36.23%) with respect to oil content. The increased levels of sulphur showed positive effect on oil content of sunflower seeds. This might be due to the role of sulphur in synthesis of oil. Sulphur is involved in the formation of glucosides and glucosinolates (mustard oil) and sulphydril-linkage and activation of enzymes which aid in biochemical reaction within the plant (Ravi *et al*., 2008) [7]. Oil yield is a function of oil content and seed yield, both the attributes increased with increasing the levels of sulphur resulting in a significant increase in oil yield (Santosh Kumar *et al*., 2011) [8]. The increase in oil content with sulphur application might be the role of sulphur in oil synthesis as sulphur is a constituent of amino acid that play a vital role in oil synthesis (Tulasi *et al*., 2014) [5].

Sulphur uptake

There was a significant increase in the uptake of S in leaf, seed, stalk and total with the application of different sources of sulphur at harvest stage of sunflower (Table 3). Among the different sources of sulphur, significantly higher S uptake at harvest was recorded with ammonium sulphate (3.66, 7.37, 4.53 and 15.56 kg ha^{-1}) in leaf, stalk, seed and total respectively, compared to gypsum and elemental sulphur and however it was on par with SSP (3.28, 6.94, 4.41 and 14.63 kg ha^{-1}). It might be the reason that sources other than ammonium sulphate used in present study are sparingly soluble and do not contain easily available form of sulphur like ammonium sulphate. Similar results were also reported by Baviskar *et al.* (2005) [9] in safflower. Different levels of sulphur showed significant influence on sulphur uptake at harvest stage of sunflower. Among the different levels of sulphur, significantly higher S uptake (4.63, 8.25, 5.33 and 18.07 kg ha^{-1}) was recorded with 45 kg S ha^{-1} in leaf, stalk, seed and total respectively compared to 30 kg S ha^{-1} and 15 kg S ha^{-1}. The increase in removal of the nutrients under sulphur application might be the outcome of increased contents of these nutrients in seed and stalk coupled with increased seed and stalk yield ha^{-1} (Singh *et al.*, 2013) [10].

Sulphur availability

Application of different sources of sulphur significantly influenced the available S in the soil after harvest of the sunflower. Among the different sulphur sources, significantly higher available S content (16.35 kg ha^{-1}) was recorded with application of ammonium sulphate (S_3) compared to SSP (S_4), gypsum (S_2) and elemental sulphur (S_1). It might be attributed to the supply of sulphur in more readily available form from ammonium sulphate compared to SSP and gypsum. Tomar (2012) [4] in linseed also found similar result. At harvest stage, the available sulphur content in soil increased from its initial status in all the treatments with increase in sulphur levels. However, significantly higher available sulphur content in soil was recorded with 45 kg S ha^{-1} and the lower with 15 kg S ha^{-1}. The higher S content of 17.55 kg ha^{-1} was recorded with L_3 (45 kg S ha^{-1}) which was significantly superior over rest of the sulphur levels. This may be due to more vegetative as well as root growth with the application of sulphur which oxidized the reduced sulphur to sulphate by microbial activity in association with the roots in the rhizosphere and in the oxidized layers of the soil (Ravi *et al*., 2010) [11]. Addition of fertilizer S known to increase available S status of soils as cropping without S input will decrease Tomar (2012) [4] in linseed.

Conclusion

From the results of the study, it can be concluded that there was significant response of sulphur fertilization on sunflower. Application of S through ammonium sulphate at the level of 45 kg ha^{-1} could be the best source of sulphur for enhancing the growth, yield, quality, sulphur uptake and availability of sunflower because of its higher solubility and availability of sulphur for plants.

Table 1: Effect of different sources and levels of sulphur on grain yield and stalk yield of sunflower

Treatments	Grain yield (kg ha^{-1})	Stalk yield (kg ha^{-1})
Sulphur sources		
S_1 – Elemental sulphur	1536.33	2352.60
S_2 – Gypsum	1592.22	2375.93
S_3 – Ammonium sulphate	1648.00	2504.29
S_4 – Single super phosphate	1632.33	2467.49
S.Em±	28.35	41.03
CD (P=0.05)	83.16	120.33
Sulphur levels (kg ha^{-1})		
L_1 – 15 kg ha^{-1}	1478.17	2313.25
L_2 – 30 kg ha^{-1}	1608.67	2403.23
L_3 – 45 kg ha^{-1}	1719.83	2558.75
S.Em ±	24.55	35.53
CD (P=0.05)	72.02	104.21
Interaction (S x L)		
S.Em ±	49.11	71.06
CD (P=0.05)	NS	NS

DAS – Days after sowing NS – Non significant

Table 2: Effect of different sources and levels of sulphur on oil content, oil yield, protein content and protein yield of sunflower grains

Treatments	Oil content (%)	Oil yield (kg ha^{-1})	Protein content (%)	Protein yield (kg ha^{-1})
Sulphur sources				
S_1 – Elemental sulphur	34.83	538.79	14.57	225.82
S_2 – Gypsum	35.19	562.27	15.60	249.56
S_3 – Ammonium sulphate	37.84	624.84	16.22	268.68
S_4 – Single super phosphate	36.23	593.35	15.76	258.33
S.Em±	0.76	15.25	0.40	8.80
CD (P=0.05)	2.23	44.72	1.16	25.81
Sulphur levels (kg ha^{-1})				
L_1 – 15 kg ha^{-1}	33.01	489.52	14.22	210.69
L_2 – 30 kg ha^{-1}	36.84	592.16	15.32	246.87
L_3 – 45 kg ha^{-1}	38.23	657.75	17.08	294.23
S.Em ±	0.65	13.20	0.34	7.62
CD (P=0.05)	1.93	38.73	1.0	22.35
Interaction (S x L)				
S.Em ±	1.31	26.41	0.68	15.24
CD (P=0.05)	NS	NS	NS	NS

DAS – Days after sowing NS – Non significant

Table 3: Effect of different sources and levels of sulphur on availability and uptake of sulphur (kg ha^{-1}) at harvest of sunflower

Treatments	Availability of S in soil after harvest	Total uptake of S (kg ha^{-1}) at harvest			
		Leaf	Stalk	Seed	Total
Sulphur sources					
S_1 – Elemental sulphur	13.62	2.74	6.20	3.72	12.49
S_2 – Gypsum	14.15	3.07	6.53	3.87	13.47
S_3 – Ammonium sulphate	16.35	3.66	7.37	4.53	15.56
S_4 – Single super phosphate	14.54	3.28	6.94	4.41	14.63
S.Em±	0.58	0.14	0.17	0.20	0.32
CD (P=0.05)	1.70	0.41	0.50	0.61	0.94
Sulphur levels (kg ha^{-1})					
L_1 – 15 kg ha^{-1}	12.28	1.81	5.36	2.96	9.96
L_2 – 30 kg ha^{-1}	14.16	3.13	6.68	4.11	13.91
L_3 – 45 kg ha^{-1}	17.55	4.63	8.25	5.33	18.07
S.Em ±	0.50	0.12	0.15	0.17	0.27
CD (P=0.05)	1.47	0.35	0.44	0.50	0.55
Interaction (S x L)					
S.Em. ±	1.00	0.24	0.30	0.34	0.53
CD (p=0.05)	NS	NS	NS	NS	NS

DAS – Days after sowing NS – Non significant

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