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A review on role of sulphur nutrition in oilseed crops

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Abstract
India is the world's biggest vegetable oil manufacturer and buyer. Oilseeds play an important role in agricultural economy of India. Oil derived from oilseed crops is considered as essential raw material for many industries. Sulphur (S) plays an important role in determining the quality of oil derived from these crops. Sulphur is required for the formation of proteins, vitamins and chlorophyll. Use of sulphur free fertilizers is one of the main reason for the shortage of sulphur in Indian soils. A balanced fertilization which includes sulphur is necessary for the quality growth of oilseed crops. Range of 30-60 kg S/ha significantly influenced crop growth, yield, nutrient uptake and economics of oilseeds. This review provides an insight about the recent research works carried out on oilseeds in terms of sulphur application.

Keywords: Sulphur, oilseeds, growth and yield attributes, nutrient uptake, economics

Introduction
India is the largest producer of oilseeds. India ranks second in groundnut production, third in production of mustard. Of all the agricultural commodities produced in India, oilseeds account for 10% of the total agricultural value. In India, oilseeds occupy an area of 24.65 million hectares, production of 31.31 million tonnes (Anon, 2018) [1]. Seven edible oilseeds which include groundnut, soybean, sunflower, rapeseed and mustard, sesame, safflower and niger are cultivated in India. In India, Madhya Pradesh is the largest producer of oilseeds followed by Gujarat and Rajasthan.

Oils have an important contribution to the human diet and industrial requirement. Oils and fats are important raw materials for the manufacturing of soaps, paints, varnishes, hair oils, lubricants, textiles, auxiliaries, pharmaceuticals, cosmetics, biodiesel and fibres etc. Oilcake and meals are used as fertilizer and in animal feed due to their rich nutrient composition which is beneficial for animals. Polyunsaturated fatty acids present in oil derived from specific species are used against coronary heart diseases. Growing oilseeds can have a major impact on the diet of humans thereby increasing food security, creating income generation. Oil or fat can be derived from both plant and animal sources but the latter is only limited source which takes more time and energy when compared to plant sources. Thus, there is a need for developing the growth, quality of oilseed crops.

After nitrogen (N), phosphorous (P) and potassium (K) sulphur is now repeatedly considered as the fourth macro nutient. Oilseeds require more amount of sulphur when compared to other crops, also its requirement in oilseeds is as high as phosphorus (Aulakh and Pasricha, 1988) [2]. It is an important plant nutrient in terms of increasing yield and quality (Kanwar and Mudahar, 1986) [8]. Cysteine, cystine and methionine are the sulphur containing amino acids thus making it one of the important factor for plant growth (Parmar *et al.*, 2018) [13]. Sulphur has also a role to play in the formation of chloroplast and chlorophyll, protein synthesis and redox reactions. Sulphur improves root growth, involves in the formation of vitamins and enzymes thus having a role in biochemical processes (Scherer *et al.*, 2008) [23]. Glucosides or glucosinolates synthesized in oilseed crops require sulphur for their synthesis. Sulphur as a constituent of proteins is necessary for the formation of disulphide bonds which are necessary to maintain a stable structure of the protein. Sulphur application increased the uptake of various macro and micronutrients in groundnut (Singh, 1999) [25].

India is having a very low global contribution of oilseeds due to its less productivity. There are various factors behind the low productivity of oilseeds, but the most significant among them is insufficient and imbalanced fertilisation. Sulphur deficiency is one of the main components behind imbalance fertilization.

The reasons for Sulphur deficiency include increased use of sulphur-free fertilisers such as urea instead of ammonium sulphate and diammonium sulphate instead of single super phosphate resulting in soil and plant sulphur deficiency. Reduced usage of insecticide-containing, pesticide-containing sulphur and insufficient application in the area of organic manures, leading to sulphur deficiency in crops. Sulphur deficiency is being recognized as a widespread problem. Sulphur deficiency reduces yield and quality of produce, making a sharp impact in the agro-based economy (Patil *et al.*, 2014) [14]. Continuous use of sulphur-free fertilizers has widened the ratio of N: P2O5: K2O: S to 14.7: 5.1: 1.6: 1 in India (TSI, 2014) [33]. Thus, there is a need for managing the sulphur levels in the soil by adopting advanced techniques.

Sulphur deficiency among soils of India growing oilseeds

Oilseed cultivation is mainly done in coarse-textured soils which are having low sulphur content. The reason behind this sulphur deficiency in coarse-textured soils is the low availability of organic matter (Takkar, 1988) [30]. ICAR based on their project on micronutrients reported that 40.7% of various soils collected across the country were found to be deficient in sulphur (Singh, 1991) [27]. Organic matter is the major source for sulphur uptake by the crop. Soils containing less than 10 ppm sulphur are stated to be deficient (Venkatesh and Sathyanarayana, 1999) [34]. The mean critical values of soil available sulphur for different oilseeds are 10.1 ppm (groundnut), 10.4 ppm (mustard), 18.8 ppm (Sunflower) and 11.7 ppm (Soybean) (Tandon, 1991) [31].

Sulphur deficiency symptoms

Leaves turn pale green, yellowish-green or complete yellow in sulphur deficient soils. Sulphur is less mobile thus sulphur deficiency first appears on younger leaves, it resembles that of nitrogen deficiency. Sulphur is easily mobilized from older leaves to the growing parts or younger leaves in the form of sulphate. However, the sulphur that gets transferred will not be sufficient to maintain normal growth resulting in small and pale green younger leaves. Sulphur deficiency reduces cell division thus leading to plant atrophy (Schnug and Haneklaus, 2005) [24]. Plants are stunted and appear to be erect under sulphur deficiency. 20-40% of the yield can be reduced in oilseeds when grown under sulphur deficient soils. In groundnut sulphur deficiency results in developing of pale yellow colour with white veins which appears on the younger leaves. Cupping of leaves, pale green to yellow colouration of younger leaves are the symptoms of sulphur deficiency in rapeseed. Leaves become pale, internodes become shorter and plant height is reduced in sunflower due to sulphur deficiency. Leaves turn yellow-green in soybean.

Different sources of sulphur used for oilseed crops

Ammonium sulphate (24% S), single superphosphate (12% S), gypsum (13% S), pyrite (22-30% S) and elemental sulphur (85-100% S) are the most commonly used sulphur-containing fertilizers in India. Phosphogypsum (16% S), magnesium sulphate (13% S), press mud (2-3% S) and sulphur sludge (10-16% S) are other sources of sulphur which are less commonly used. Pyrites and elemental sulphur should be applied 20-25 days before planting because elemental sulphur requires oxidation, pyrites is a slow-release fertilizer (Tivari *et al.*, 1984) [32]. Gypsum and phosphogypsum are suitable for all types of soils and crops requiring calcium like groundnut (Rao *et al.*, 2013) [18]. Single superphosphate is the best source of fertilizer for oilseeds as it supplies both P and S. For soils deficient in nitrogen and sulphur ammonium sulphate can be recommended.

Assessment of sulphur deficiency

Soil analysis: To estimate the available sulphur of soils, a variety of chemical methods have been produced and validated. The main thing is that the method chosen should be reliable and correlated with crops which are applied with sulphur. In India, the most widely used approach involves soil sulphur extraction with 0.15% CaCl2 solution. Via this approach, soils containing less than 10 ppm sulphur are known to be poor or deficient (Williams and Steinbergs, 1959) [37].

Plant analysis: For carrying out plant analysis, standard analytical methods are followed. In-plant digest obtained by dry ashing by wet digestion with HNO_3 and $HClO_4$, sulphur is estimated (Chaudhary and Cornfield, 1966) [5]. For eg., if a cereal tissue tested for sulphur contains less than 0.2% sulphur then it is known to be sulphur deficient.

Role of Sulphur in Oilseed crops

Effect of sulphur on growth and yield attributes in Oilseeds

Singh *et al.* (2013) [26] experimented on linseed and reported that plant height, dry matter accumulation, primary and secondary branches/plant, capsules/plant, seeds per capsule and 1000 seed weight were significantly affected by the application of 20 kg S/ha. Prajapat *et al.* (2012) [16], experimented on sesame and found out that application of 30 kg S/ha increased plant height at 60DAS (106.6cm), harvest (111.7cm) and dry matter accumulation at harvest (117.26g/meter row length) in Sesame and they also stated that application of 45 kg S/ha increased dry matter accumulation at 60 DAS (99.47 g/meter row length). Bhavani and Meena (2015) [3] reported that application of 40 Kg S/ha as bentonite maximised yield attributes like plant height (191 cm), dry matter/plant (55.8 g), primary branches (7.2) secondary branches/plant (14.6), siliqua/plant (336.3), seeds/siliqua (16.8) and 1000 seed weight (6 g) in mustard over control. In an experiment conducted on sunflower by Saleem *et al.* (2019) [11] it was reported that application of 20 kg S/ha improved plant height (161.8 cm), stem girth (4.8 cm), flower head diameter (15.4 cm), number of achene/head (787), 1000 seed weight (50.29 g) and achene yield (650.33 kg/ha) when compared to control (156.37 cm, 3.90 cm, 14.3 cm, 679, 47 g, 570 kg/ha). Leaf area index (4.80, 4.47), crop growth rate (0.97, 1.03 g/sq.cm/day), relative growth rate (0.010, 0.009 g/g/day) and net accumulation rate (0.38, 0.38 g/sq.cm/day) of sunflower increased significantly at 75 DAS-harvest due to the application of sulphur @ 50 kg/ha in both the years (Kapila and Yashbir**,** 2009) [9]. Pavani *et al.* (2012) [15], experimented on Sunflower, stated that application of 30 kg S/ha maximized the plant height (178.5 cm), dry matter accumulation (111.4 g/plant), stem girth (10.67cm), head diameter (20.27cm), number of filled seeds per head (767), seed yield (2048 kg/ha) and stalk yield (4028 kg/ha) over control (163.1cm, 100.5g/plant, 9.87cm, 17.43cm, 680.3, 1732kg/ha & 3696kg/ha). Piri and Sharma (2006) [6], revealed that plant height (172.0, 176 cm), dry matter accumulation (78.2, 87.6 g/plant), leaf area index (3.40, 3.50), relative growth rate (12.88, 11.63 mg/g/day) and net assimilation rate (0.59, 0.55 mg/sq.m/day) increased with the use of sulphur at the rate of 45 kg/ha during two subsequent years over control (150 & 162.2 cm, 51.2 &56.8 g/plant, 1.70 & 1.90, 8.70 &

7.93 mg/g/day, 0.31 &0.27 mg/sq.m/day) at 90 DAS -harvest in Mustard. Pachauri and Trivedi (2012) [17], noted that Sulphur application in Mustard at the rate of 90 kg/ha efficiently improved plant height (171.2cm), no. of pods per plant (374.7), no. of seeds per plants (15.2), 1000 seed weight (5.25g). Sarkar and Banik (2002) [22], revealed that application of sulphur in Sesame at the rate of 50 kg/ha resulted in increased leaf area index (0.218), crop growth rate (1.013 g/plant/day), relative growth rate (0.039 g/g/day) and net assimilation rate (0.012 g/sq.cm/day) at 70-95 DAS over sulphur @ 0 kg/ha (0.173, 1.358 g/plant/day, 0.011 g/g/day,0.015 g/sq.cm/day). Kapila and Yashbir (2009) [9], concluded that application of sulphur in sunflower at the rate of 50 kg/ha increased total dry matter production (113.63, 112.75 g/plant) at harvest over control (104.25, 96.01 g/plant) in both the years. Different attributes of rapeseed-mustard like plant height (142 cm), primary branches per plant (4.5), secondary branches per plant (6.0), siliquae per plant (228), seeds per siliquae (21.9), 1000-seed weight (3.75g), seed yield (1436 kg/ha), stover yield (5388 kg/ha) and harvest index (21.2%) were increased by the application of sulphur @ 20 kg/ha when compared to control (141cm, 4.4, 5.4, 212, 20.9, 3.58g, 1366kg/ha, 5176 kg/ha & 21.2%) as confirmed by Virender and Parvender (2011) [36]. Santosh *et al.* (2009) [20], noted that plant height at 90 DAS (157cm), leaf per plant at 90 DAS (4.1), branches per plant at 60 DAS (21.5), no. of siliquae per plant (330), siliquae length (7.05cm), seed per siliqua (15.4g), test weight (4.68 tonnes/ha), seed yield (1.25 tonnes/ha) and stalk yield (4.20%) of mustard improved efficiently due to the application of sulphur at the rate of 45 kg/ha than other levels of sulphur. Singh and Thenua **(**2016) [28] based on their experiment on mustard noted that application of 40 kg S/ha efficiently improved growth attributes like plant height (145.12 cm), no. of primary branches/plant (6.51), no. of secondary branches/plant (10.58) and dry weight (28.95 g/plant) when compared to other levels. Perumal *et al.* (2019) [21] noted that application of 40 kg S/ha as ammonium sulphate efficiently improved plant height (174.24 cm), leaf area index (4.90), dry matter production (5438.28 kg/ha) and seed yield (1790 kg/ha) of sunflower at harvest when compared to other treatments.

Singh *et al.* (2013) [26], reported that seed and stover yield were increased by 18.7 and 10.6% over control by the application of 20 kg S/ha in Linseed. Prajapat *et al.* (2012) [16], showed that Sulphur application in Sesame had a significant impact on growth and yield. Solanki *et al.* **(**2018) [19], experimented on Mustard, reported that application of sulphur had a significant effect on seed yield and also stated that application of 30, 40, 50 kg S/ha increased Mustard yield to 17.5, 18.7, 9.3 q/ha over control (15.1 q/ha). Kumar *et al.* (2002) [29], conducted an experiment on Mustard and reported that seed yield (1.636 tonnes/ha), siliquae per plant (452.43), silique length (5.99 cm), seeds per siliquae (12.50), 1000 seed weight (4.05 g) recorded high when compared to other sources due to the application of Sulphur in the form of gypsum. Sonalki *et al.* **(**2018) [19] reported that application of 50 kg s/ha resulted in maximum sulphur (15.7 kg/ha) availability after harvest when compared to control (12.0 kg/ha) in Mustard. In an experiment conducted on mustard by Bhavani and Meena (2015) [3] it was concluded that application of 40 kg S/ha via bentonite resulted in higher seed (2.45 tons/ha) and stover yield (6.78 tons/ha) when compared to other levels and sources**.** Paritosh *et al.* (2013) [12], revealed that seed yield (20.98 q/ha, 23.8 q/ha), stalk yield (78.13 q/ha, 82.98 q/ha), biological yield (99.12 q/ha, 106.23 q/ha), harvest index (21.02%,21.72%) increased significantly due to the application of 40 kg S/ha in sunflower during two subsequent years. Kapila and Yashbir (2009) [9], concluded that application of 50 kg S/ha maximized seed yield (1995.1, 1995.7 kg/ha), biological yield (4163.3, 4196.5 kg/ha) and harvest index (47.9, 46.9%) of sunflower during 2005 and 2006 over control (1787.6 & 1730.4 kg/ha, 3899.2 & 3651.4 kg/ha, 45.8 & 48.7%). Manoj Pandey and Javed Ali (2012) [10] reported that application of sulphur as ammonium sulphate in linseed maximized seed yield (15.9, 16.55 t/ha), stover yield (31.28, 32.66 t/ha) and aslo reported that application of 40 kg S/ha as a level increased seed yield (17.66, 18.26 t/ha) and stover yield (34.88, 36.87 t/ha). Bhupender *et al.* (2013) [4] based on their experiment on mustard reported that seed yield (1.22 t/ha) and stover yield (2.50 t/ha) had an improved performance when compared to control (0.64, 1.92 t/ha). Sonalki *et al.* (2018) [19], concluded that the application of 30,40,50 kg S/ha in mustard increased stover yield from 39.1 (control) to 44.1, 47.0, 48.1 q/ha**.** Venkatesh *et al.* (2002) [35], reported that pod yield (3.098 tonnes/ha), haulm yield (3.810 tonnes/ha), shelling percentage (74.81%) and 100-kernel weight (57.20 g) increased significantly due to sulphur application in the form of gypsum at the rate of 30 kg/ha over control 2.121tonnes/ha, (2.454tonnes/ha, 71.90%, 53.38 g) in Groundnut. Prajapat *et al.* (2012) [16], revealed that application of 45 kg S/ha increased the number of capsules per plant (26.1) and the number of seeds per capsule (43.2) in Sesame**.** Seed yield (2.17, 2.26 t/ha) and stover yield (6.57, 6.77 t/ha) of mustard were significantly affected with the use of sulphur @ 90 kg/ha during two subsequent years **(**Pachauri and Trivedi**,** 2012) [17]. Sarkar and Banik (2002) [22], stated that capsules per plant (45.88), capsule length (2.26cm), seeds per capsule (45.55), 1000-seed weight (3.50g) and seed yield (801 kg/ha) of sesame were increased by the application of sulphur at 50 kg/ha over control (44.83, 2.08cm, 44.89, 3.45g & 752 kg/ha). Application of sulphur at 60 kg/ha in mustard maximized seed yield (1.809 tonnes/ha), siliquae per plant (475.85), siliquae length (6.17 cm), Seeds per siliquae (13.42) and 1000 seed weight (4.43 g) over control (1.378 tonnes/ha, 411.75, 5.55 cm, 10.83, 3.62 g) (Kumar *et al.***,** 2002) [29]. Yield attributes of mustard like no. of siliqua/plant (232.14), no. of seeds/siliqua (11.44), test weight (4.41 g), biological yield (37.22 q/ha), grain yield (10.31 q/ha) and harvest index (27.54) were influenced due to application of 40 kg S/ha (Singh and Thenua**,** 2016) [28]. Prajatpat *et al.* (2012), stated that seed yield (1724 kg/ha) of sesame increased significantly at 45 kg S/ha whereas stick yield (1360 kg/ha) responded only up to 30 kg S/ha.

b) Effect of Sulphur on quality of oilseeds:

In an experiment conducted by Singh *et al.* (2013) [26] on linseed, it was revealed that application of 20 kg S/ha increased oil content and the magnitude of increase was 4.4% over control. Saleem *et al.* (2019) [11] reported that oil content in sunflower varied from 39.3% (control) to 42.2% (20 kg S/ha) due to sulphur usage. Paritosh *et al.* (2013) [12], stated that the application of sulphur @ 40 kg/ha in sunflower increased oil content (28.88%, 29.12%) during two subsequent years. Application of sulphur in the form of gypsum @ 30 kg/ha in groundnut had significant impact on protein content (29.06%), protein yield (0.668tonnes/ha), oil content (49.47%) and oil yield (1.138tonnes/ha) over control (22.68%, 0.340tonnes/ha, 47.22%, 0.719tonnes/ha) **(**Venkatesh *et al.***,** 2002) [35].

Pachauri and Trivedi (2012) [17], stated that oil content of mustard (41.81, 42.12%) increased due to the application of 90 kg S/ha in both the years. Singh *et al.* (2013) [26] concluded that Sulphur application in linseed had a significant impact on iodine value, iodine value decreased at 40 kg/ha Sulphur application over the control.

Kumar *et al.* (2002) [29], stated that oil yield (0.672 tonnes/ha) in Mustard increased with the use of gypsum as a sulphur source and it was also noted that application of sulphur at the rate of 60 kg/ha increased oil yield (0.756 tonnes/ha) over control (0.528 tonnes/ha). Oil content (39.4%) and oil yield (566 kg/ha) responded significantly due to the application of sulphur at 20 kg/ha over control (39.2%, 537kg/ha) in Rapeseed-mustard **(**Virender and Parvender, 2011) [36].

Santosh *et al.* (2009) [20], stated that application of sulphur at the rate of 45 kg/ha recorded highest oil content (39.9 kg/ha), oil yield (522%), protein content (17.9 kg/ha) and protein yield (222 Rs/ha) than other levels of sulphur. Singh and Thenua (2016) [28] stated that the oil content of mustard seed increased from 38.61 to 39.04% due to the application of 40 kg S/ha.

c) Effect of sulphur on nutrient uptake of oilseeds:

It was concluded by Singh *et al.* (2013) [26], that there was increased removal of NPKS due to the increased levels of Sulphur application. 20 kg S/ha showed a significant effect on sulphur uptake (0.225%) in straw whereas control had 0.172% **(**Saleem *et al.*, 2019) [11]. Manoj Pandey and Javed Ali (2012) [10] reported that sulphur use efficiency of 9.7, 10.1 kg/kg S and 15.9, 3.8 kg/kg S during two consecutive years was obtained due to usage of Ammonium sulphate, application of 20 kg S/ha. N (41.3 kg/ha), P (11.7 kg/ha), K (40.9 kg/ha), S (20.2 kg/ha) and Zn (92.8 g/ha) uptake of mustard were influenced due to application of 80 kg S/ha **(**Bhupender *et al.*, 2013) [4]**.** Venkatesh *et al.* **(**2002) [35], conducted an experiment on Groundnut and reported that application of sulphur @ 45 kg/ha in the form of gypsum maximized S uptake by kernels (10.37 kg/ha) and S uptake by straw (4.62 kg/ha) over control (4.39 kg/ha, 1.91 kg/ha). N (131.0 kg/ha), P (31.1 kg/ha), K (87.92 kg/ha) and S (27.47 kg/ha) uptake by Mustard were significantly impacted due to the application of 90 kg S/ha over control (83.86, 19.8, 53.91, 11.20 kg/ha) as noted by Pachauri and Trivedi **(**2012) [17]. Kumar *et al.* (2002) [35], revealed that N (95.17 kg/ha), P (14.42 kg/ha), K (74.79 kg/ha), S (29.84 kg/ha) and Fe (0.99 kg/ha) uptake by Mustard significantly increased due to the application of sulphur as gypsum. Santosh *et al.* (2009) [20].

Reported that sulphur uptake (20.7 kg/ha) in Indian mustard recorded highest due to the application of sulphur @ 45 kg/ha. Total N (39.34 kg/ha), total P (10.67 kg/ha) and total S (17.73 kg/ha) uptake by mustard was significantly influenced under 40 kg S/ha application (Singh and Thenua, 2016) [28]. Sulphur use efficiency decreased in the order of gypsum>single super phosphate>elemental sulphur **(**Venkatesh *et al.***,** 2002) [35]. N (108.58 kg/ha), P (16.77 kg/ha),K (85.06 kg/ha), S (33.77 kg/ha) and Fe (1.87 kg/ha) uptake by Mustard recorded high with the application of sulphur @ 60 kg/ha over control (68.12, 10.19, 54.73, 20.21 & 0.63 kg/ha) (Kumar *et al.*, 2002) [29].

d) **Effect of sulphur on economics of Oilseeds:** Bhavani and Meena (2015) [3] stated that the application of 40 kg S/ha in mustard as bentonite maximised the net returns (₹ 59,200) and B: C ratio (3.1). Pachauri and Trivedi (2012) [17], revealed that cost of cultivation (Rs.12928), net returns (Rs.42018) and net returns per invested (3.25) increased due to the application of sulphur @ 90 kg/ha in Mustard. Kumar *et al.* **(**2002) [29], stated that application of sulphur @ 60 kg/ha in the form of gypsum significantly impacted the gross income (Rs. 20964.80), cost of cultivation (Rs. 10304.30), net income (Rs. 10660.48) and B: C ratio (2.034) when compared to other sources and levels of sulphur in Mustard. Cost of cultivation (Rs. 9775/ha), net returns (Rs. 13568/ha) and B: C ratio (2.45) of mustard recorded highest with the use of sulphur at 45 kg/ha (Santosh *et al.***,** 2009) [20].

Conclusion

- As sulphur fertilizers are not commonly used there is a widespread deficiency of sulphur in Indian soils leading to the less productivity of oilseeds.
- Sulphur deficiency results in reduced usage efficiency of applied NPK.
- To maintain efficient targets of agricultural production through balanced crop nutrition sulphur application should not be neglected.
- Proper yield combined with good quality is an essential requirement for oilseeds; this quality can only be maintained when the plant is supplied with enough sulphur.
- Based on the experiments reviewed it can be stated that application of sulphur @ 30-60 kg/ha significantly influenced the growth, yield, nutrient uptake and economics of oilseed crops.
- Sulphur can be supplied through sources like gypsum, elemental sulphur, pyrites and phosphogypsum. It can also be applied via primary nutrient containing fertilizers such as ammonium sulphate, SSP, sulphate of potash.

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