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Effect of Sulphur Application in Oilseed Crops: A Review

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ABSTRACT

Oilseeds play a pivotal role in India's agricultural economy, with oil derived from these crops serving as a fundamental raw material for various industries. Sulphur (S) plays a crucial role in augmenting both the yield and quality of oilseed crops. Achieving a balanced fertilization strategy that incorporates S is imperative for fostering the high-quality growth of oilseed crops. Several researches indicate that S application in the range of 20-60 kg ha^{-1} substantially influences crop growth, yield, nutrient uptake and the economic aspects of oilseed cultivation. This review offers valuable insights into the latest research endeavors conducted in the realm of oilseed crops, specifically concerning sulphur application.

Key words: Economics, Growth, Oilseed, Quality, Sulphur, Yield.

India stands as a prominent player in the global oilseed industry, holding the position of one of the leading cultivators and importers of edible oils. Within the agricultural landscape of India, oilseed cultivation spans over 27.13 million hectares, yielding a total production of 33.21 million tones and at an average productivity of 1214 kg/ha (Anonymous, 2020). The varied agro-ecological conditions prevalent in the nation provide a conducive environment for the cultivation of annual oilseed crops. These encompass a range of seven edible oilseeds, namely groundnut, rapeseed and mustard, soybean, sunflower, sesame, safflower and niger, along with two non-edible oilseeds, castor and linseed (Table 1).

Sulphur (S) holds the 13th position in terms of abundance in the Earth's crust and stands as the fourth primary plant nutrient, following nitrogen (N), phosphorus (P) and potassium (K). Typically, oilseed crops exhibit a comparable demand for S as they do for P (Kamal *et al.,* 2023). Sulphur assumes a vital role in the nutritional requirements of oilseed crops, serving as a crucial component within S-containing amino acids like cystine, cysteine and methionine (Kamal *et al*., 2023a; Parmar *et al.,* 2018). Sulphur participation in the creation of vitamins and enzymes underscores its crucial involvement in various biochemical processes (Kamal *et al*., 2024; Scherer *et al.*, 2008). A pivotal role of S in proteins or polypeptides lies in the establishment of disulfide bonds between polypeptide chains. These disulfide linkages play a crucial role in stabilizing and shaping the configuration of proteins (Singh, 1999). Factors contributing to S deficiency encompass the escalated utilization of S-free fertilizers like urea in lieu of ammonium sulphate and diammonium sulphate instead of single superphosphate (Nagaram, 2020). The prevalence of S deficiency is increasingly acknowledged as a widespread issue. This deficiency in S significantly diminishes both the yield and quality of agricultural produce, exerting a pronounced impact on the agro-based economy (Patil *et al*., 2014). The persistent utilization of S-free fertilizers has expanded the ratio of N: P_2O_5: K_2O: S to 14.7: 5.1: 1.6: 1 within the agricultural practices in India (TSI, 2014). Therefore, there is a necessity to address and manage S levels in the soil through the adoption of advanced techniques. Sulphur application to the soil can be facilitated using various suitable carriers, such as gypsum, elemental S, ammonium sulphate and potassium sulphate, among others. Notably, in soils facing sulphur deficiency, gypsum and elemental sulphur are extensively employed as sulphur-supplying sources. This paper provides a concise overview of the research conducted at various locations in India and abroad concerning the subject under investigation. The findings are presented and reviewed under the following categories:

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Methodology

Only papers that offer guidance on accomplishing a literature review method were considered. This study conducted literature evaluations specifically focused on the effect of sulphur application in oilseed crops. We have used different keywords like growth, yield, quality and economics. Initial pertinence was assessed for each manuscript based on the title. We have gathered about 150-200 papers from various publishing agencies, selecting them based on keywords and their possible role in production. We collected the complete citation, which includes the author, year, title and abstract, for further scrutiny. We conducted a comprehensive search using three commonly used databases: Google Scholar, Web of Science and EBSCOhost. To conduct the literature review, we had to examine the abstracts of the 100 papers in order to ascertain their pertinence to the research matter.

Effect of sulphur application on growth parameters

Singh *et al*. (2023) reported that application of 60 kg S/ha produced maximum plant height (203.3 cm at 90 DAS), leaf area index (3.78 at 90 DAS), No. of leaves/plant (45.75 at 90 DAS), primary branches at harvest/plant (6.13), secondary branches at harvest/plant (17.55) in mustard, which were significantly higher over control. Bhavana *et al*. (2022) reported that application of 40 kg S ha^{-1} produced maximum plant height at harvest (100.8 cm), dry matter at harvest (2475 g/m^2) and leaf area index at 60 DAS (1.43) in sesame which were significantly higher over control. Devi *et al.* (2022a) conducted research and purported that application of 50 kg N + 40 kg S ha^{-1} significantly increased plant height (56.95 cm), number of nodules (48.20 $plant^{-1}$), dry matter accumulation (42.98 g $plant^{-1}$) and crop growth rate (7.11 g/m^2/plant) in groundnut, which were significantly higher over 30 kg N + 0 kg S ha^{-1} by 10.3, 16.6, 22.9 and 21.7 per cent, respectively. Khan *et al*. (2021) observed that application of 45 kg S ha^{-1} produced more plant height (125.21 cm), maximum dry weight/plant (19.48 g) and number of branches/plant (3.47) in sesame which were significantly higher over other lower doses of sulphur. Dileep *et al.* (2021) conducted a field experiment on groundnut and examined that application of 40 kg S/ha resulted in more plant height (59.31 cm), dry weight accumulation (56.73 g/plant), number of nodules (47.53 $plant^{-1}$), crop growth rate (13.82 g/m^2/day), relative growth rate (0.008 g/g/day) at harvest, which were significantly higher over application of 30 kg and 20 kg S/ha. Perumal *et al.* (2019) noted that application of 40 kg S/ha through ammonium sulphate efficiently improved plant height (174.24 cm), leaf area index (4.90) and dry matter production (5438.28 kg/ha) at harvest when compared to other treatments in sunflower. Saleem *et al*. (2019) studied that application of 20 kg S ha^{-1} in sunflower improved plant height (161.8 cm) and stem girth (4.8 cm) when compared to control. Yadav *et al.* (2018) conducted a study at Rajasthan and professed that application of 75 kg S/ha in groundnut gave higher plant height (26 cm), dry matter accumulation (489.50 g/m row length), crop growth rate between 35-70 DAS (13.09 g/m^2/day), relative growth rate between 35-70 DAS (67.14 mg/g/day), number of nodules (64.01 $plant^{-1}$), number of effective nodules (57.66 $plant^{-1}$), fresh weight of nodules (233.90 mg $plant^{-1}$), dry weight of nodules (105.14 mg $plant^{-1}$), which were statistically at par with application of 60 kg S/ha and significantly higher over 45 kg , 30 kg and 15 kg S/ha. Pancholi *et al.* (2017) concluded that use of 60 kg S ha^{-1} significantly increased number of nodules (65.3 $plant^{1}$) and dry matter accumulation (553.2 g/meter row length) compared to other lower doses of sulphur in groundnut. Parakhia *et al.* (2016) conducted a pot experiment in soybean and purported that application of 15 mg S kg^{-1} significantly increased dry matter accumulation in different plant parts at 45 DAS leaves (2.749 g), shoot (2.694 g), root (0.376 g), total plant (5.789 g) and at harvest leaves (3.165 g), shoot (5.767 g), root (0.476 g), total plant (9.408 g), which were significantly higher over 0 mg S kg^{-1} by 27.8, 23.6, 8.0, 23.7 and 33.7, 13.0, 25.2, 19.8 per cent, respectively. Saini *et al.* (2016) conducted a study at Gujarat and revealed that application of 40 kg S ha^{-1} significantly increased number of root nodules (93.7 $plant^{-1}$), dry matter accumulation (29.8 g $plant^{-1}$) and plant height (24.4 cm) compared to 20 kg S ha^{-1} in groundnut. Meena and Meena (2015) reported that application of 40 kg S/ha (Bentonite) maximized plant height (191 cm), dry matter/plant (55.8 g), primary branches/plant (7.2), secondary branches/plant (14.6) in mustard over control. Noman *et al.* (2015) conducted research at IARI, New Delhi and averred that application of 40 kg S ha^{-1} significantly increased number of branches (5.34 $plant^{-1}$), plant height (35.5 cm) and leaf area index (3.10) over 20 kg S ha^{-1} and control in groundnut. Veeranagappa *et al.* (2015) conducted a field experiment at Karnataka and concluded that RDF + FYM + 45 kg S ha^{-1} through gypsum produced highest plant height (33.72 cm) at harvest which was significantly higher over control by 34.9% in groundnut. Layek *et al.* (2014) investigated that increasing the levels of sulphur up to 40 kg ha^{-1} in soybean significantly increased plant height (58.01 cm), number of branches at harvest (3.07), dry matter at harvest (36.5 g $plant^{-1}$), leaf area index at 90 DAS (2.89), crop growth rate at

Table 1: Major oilseed crops grown in India.

Common name	Botanical name	Family	Oil content (%)
Groundnut	*Arachis hypogaea* L.	Leguminosae	45
Soybean	*Glycine max* L.	Leguminosae	20
Sunflower	*Helianthus annuus* L.	Asteraceae	45-50
Sesamum	*Sesamum indicum* L.	Pedaliaceae	50
Niger	*Guizotia abyssinica* L.	Asteraceae	30-40
Castor	*Ricinus communis* L.	Euphorbiaceae	48
Safflower	*Carthamus tinctorious* L.	Asteraceae	24-36
Linseed	*Linum usitatissimum* L.	Linaceae	33-47
Rapeseed/Mustard	*Brassica spp.* L.	Brassicaceae	37-49

60-90 DAS (0.38 g/plant/day), number of nodules at 45 DAS (54.15 plant^{-1}), nodules dry weight at 45 DAS (676.04 mg plant^{-1}), it was statistically at par with application of 30 kg S ha^{-1} and significantly higher over 20 kg S, 10 kg S and 0 kg S ha^{-1}. Rao *et al.* (2013) conducted a field experiment at Andhra Pradesh and inferred that the treatment comprised of RDF (60 kg N + 50 kg P_2O_5 + 40 kg K_2O/ha) + 45 kg S/ha through gypsum recorded higher plant height (71.45 cm) compared to other treatments in groundnut. Singh *et al.* (2013) reported that application of 20 kg S ha^{-1} significantly affected plant height, dry matter accumulation, primary and secondary branches/plant in linseed. Pavani *et al.* (2012) conducted an experiment on Sunflower and found that application of 30 kg S/ha maximized the plant height (178.5 cm), dry matter accumulation (111.4 g/plant) and stem girth (10.67 cm) over control. Kumar *et al.* (2011) conducted a field experiment in sunflower and reviewed that application of 45 kg S ha^{-1} significantly increased plant height (85.0 cm), stem girth (7.0 cm), leaf area index (1.17), dry matter accumulation at harvest (82.0 g plant^{-1}), CGR (9.4 g/m^2/day) and RGR (0.61 g/g/day) at maturity which were significantly higher over 30 kg S, 15 kg S and 0 kg S ha^{-1}. Shelke *et al.* (2010) conducted a field experiment at Pune and reproduced that use of RDF + 500 kg gypsum ha^{-1} (250 kg gypsum ha^{-1} at the time of sowing and 250 kg gypsum ha^{-1} at the time of peg formation) + 5 t FYM ha^{-1} significantly increased plant height (41.1 cm), leaf area (25.11 dm^2 plant^{-1}) and dry matter accumulation (36.42 g plant^{-1}) compared to other sources of sulphur and absolute control in groundnut. Kumar *et al.* (2008) averred that increasing the level of sulphur up to 60 kg ha^{-1} significantly increased plant height (28.52 cm), primary branch (5.83 plant^{-1}), secondary branch (2.82 plant^{-1}), dry matter accumulation (28.42 g plant^{-1}), number of nodules (69.33 plant^{-1}), root and stem biomass (21.97 g plant^{-1}), which were statistically at par with application of 40 kg S ha^{-1} and significantly higher over 20 kg S ha^{-1} and control in groundnut. Kumar and Yadav (2007) conducted an experiment in mustard and inferred that increasing the levels of sulphur up to 45 kg ha^{-1} produced highest plant height (173.9 cm), higher number of primary branch (7.4 plant^{-1}), leaf area index (5.5) and dry matter accumulation (54.1 g plant^{-1}), which were significantly higher over control by 17.1, 54.1, 30.9 and 10.8 per cent, respectively. Rao and Shaktawat (2001) carried out an experiment at Udaipur, Rajasthan and averred that application of 250 kg gypsum ha^{-1} in groundnut produced higher number of branches plant^{-1} (4.7), leaf area index (4.43) and root dry weight plant^{-1} (0.72 g), which were significantly higher over control by 11.90, 6.86 and 7.46 per cent, respectively.

Effect of sulphur application on phenological parameters

Verma *et al.* (2018) conducted a field experiment and reviewed that progressive increase in doses of sulphur significantly increased number of days taken to 50% flowering. Significantly highest days taken to 50% flowering (61.18) were recorded with the application of 50 kg S ha^{-1} followed by 40 kg S ha^{-1} (59.99), 30 kg S ha^{-1} (59.05), 20 kg S ha^{-1} (58.50) and 10 kg S ha^{-1} (57.74). The lowest number of days taken to 50% flowering (57.48) of Indian mustard were recorded in control plot. Charan *et al.* (2013) conducted research at Bihar in mustard and avouched that days taken to 50% flowering and maturity were increased with increasing levels of sulphur up to 60 kg ha^{-1} but non-significant difference was recorded among all the levels. Kumar and Kumar (2008) reported that sulphur application non significantly affected days taken to 50% flowering and maturity in mustard.

Effect of sulphur application on yield attributes, yield and quality parameters

Singh *et al*. (2023) conducted an experiment in mustard and revealed that application of 60 kg S ha^{-1} produced higher number of siliquae (340 plant^{-1}), length of siliquae (5.03 cm), number of seeds (16.93 siliqua^{-1}), stem girth (6.25 cm), test weight (5.38 g), seed yield (2.71 t ha^{-1}), stover yield (5.11 t ha^{-1}) and biological yield (7.82 t ha^{-1}), which were significantly higher over control. Manoj *et al.* (2023) averred that application of 45 kg S ha^{-1} in soyabean gave significantly higher seed yield (1870 kg ha^{-1}) and straw yield (3179 kg ha^{-1}) which was at par with 30 kg S ha^{-1} (1773 and 3028 kg ha^{-1}), respectively. Sulphur being a structural component of glucosinolate, glucosidase enzyme, constituent of acetyl- Co A carboxylase and glycerol is responsible for higher fatty acid and oil synthesis in mustard seeds as observed by Bhinda and Singh (2023) who discerned that application of S @ 40 kg ha^{-1} in Indian Mustard registered maximum oil content (40.1%), oil yield (739 kg ha^{-1}), seed yield (1.84 t Sufficient supply of ha^{-1}) and stover yield (4.91 t ha^{-1}). Similar findings were reported by Singh *et al.* (2022) when Sulphur application rose to 60 kg ha^{-1} and integrated with 6 t FYM ha^{-1} and 2 kg B ha^{-1} in mustard crop. Bhavana *et al*. (2022) reported that application of 40 kg S ha^{-1} in sesame produced maximum capsules/ plant (29.1), seeds/capsule (39.3), test weight (1.69 g), seed yield (673 kg/ha), stover yield (1779 kg/ha), oil content (41.5%) and oil yield (282 kg/ha), which were significantly higher over control. Devi *et al*. (2022a) conducted a field experiment and purported that application of 50 kg N + 40 kg S/ha produced highest number of pods (20.60 plant^{-1}), seed index (41.17 g), pod yield (2741 kg/ha) and haulm yield (4371 kg/ha) in groundnut, which were significantly higher over 30 kg N + 0 kg S ha^{-1} by 51.5, 17.2, 36.7 and 16.9 per cent, respectively. Khan *et al*. (2021) reported that application of 45 kg S ha^{-1} in sesame produced maximum capsules/plant (41.00), seeds/capsule (55.33), test weight (3.42 g), seed yield (1.40 t/ha) and stover yield (6.91 t/ha) which were significantly higher over other lower doses of sulphur. Dileep *et al.* (2021) reported that application of 40 kg S/ha produced higher number of pods (22.65 plant^{-1}), number of kernels per pod (2.01), shelling out percentage (72.22), seed index (38.57 g), seed yield (2900 kg/ha) and haulm yield (4479 kg/ha), in groundnut, which were significantly higher over application of 30 kg and 20 kg S/ha. Indu and Singh (2020) reported that Seed yield was higher with application at 50 kg S ha^{-1} (1476.71 kg ha^{-1}) compared to control (1035.01 kg ha^{-1}) in sunflower. Hinduja *et al.* (2020) conducted a field experiment at Prayagraj (U.P.) and observed that application of 70 kg/ha phosphorous + 40 kg/ha sulphur significantly improved haulm, pod and kernel yield of groundnut over 40 kg/ha phosphorous and 20 kg/ha sulphur by 25.5, 16.8 and 21.5 per cent, respectively. Kalaiyarasan *et al*. (2020) reported that highest oil content (40.68% and 41.65%) with application 60 kg S ha^{-1} over control treatment (37.67% and 38.19%) in first and second crop respectively in sunflower. Krishna *et al*. (2020) professed that highest shelling out percentage (69.50) and pod yield (1.97 t ha^{-1}) of groundnut was recorded with application of 40 kg S ha^{-1} + NAA 50 ppm at 20 and 40 DAS which was 8.3 and 12.5 percent higher over control respectively. Yadav *et al*. (2020) concluded that increasing the levels of sulphur up to 60 kg/ha progressively increased protein content (23.89%), oil content (44.87%), oil yield (695.99 kg/ha), which were statistically at par with application of 40 kg S/ha and significantly higher over 20 and 0 kg S/ha by 12.0, 11.0, 37.5 and 20.1, 20.8, 123.4 per cent, respectively in groundnut. Kumar *et al*. (2019) reported that application of 45 kg S ha^{-1} in sesame produced maximum capsules/plant (56.33), seeds/capsule (55.67), seed yield (668.70 kg/ha) and stover yield (1889.17 kg/ha), oil yield (63.24 q/ha) and oil content (46.87%) which were significantly higher over control. Perumal *et al.* (2019) reported that application of 40 kg S/ha through ammonium sulphate efficiently improved seed yield (1790 kg/ha) when compared to other treatments in sunflower. Saleem *et al*. (2019) studied that application of 20 kg S ha^{-1} in sunflower improved flower head diameter (15.4 cm), number of achene/head (787), test weight (50.29 g) and achene yield (650.33 kg/ha) when compared to control. Yadav *et al.* (2019) averred that application of 75 kg S/ha significantly increased number of pods (22.55 $plant^{-1}$), number of kernel (1.98 pod^{-1}), seed index (69.67 g), kernel yield (1376 kg ha^{-1}), shelling out percentage (72.13), protein content (24.30%), oil content (44.61%) and oil yield (620.84 kg ha^{-1}), in groundnut which were significantly higher over 15 kg S/ha by 62.4, 27.7, 28.0, 83.9, 10.9, 25.3, 20.8 and 123.1 per cent, respectively but these were statistically at par with 60 kg S/ha. Yadav *et al.* (2018) conducted a study at SKN College of Agriculture, Jobner and concluded that increasing the levels of sulphur up to 75 kg/ha significant increased pod yield (1903 kg/ha) and biological yield (5482 kg/ha), in groundnut which were statistically at par with 60 kg S/ha but significantly higher over 45, 30 and 15 kg S/ha. Banu *et al*. (2017) reviewed that application of 40 kg S/ha produced maximum biological yield (9854 kg/ha), haulm yield (6489 kg/ha) and pod yield (3365 kg/ha) compared to other lower doses of sulphur in groundnut. Manaf *et al.* (2017) conducted research at Pakistan and asserted that application of Gypsum (400 kg ha^{-1}) significantly improved biological and seed yield of groundnut over control by 32.4 and 55.3 per cent, respectively. Nagar *et al.* (2017) averred that application of 60 kg S/ha significantly increased protein content (39.27%), protein yield (524.40 kg ha^{-1}), oil content (22.00%) and oil yield (292.40 kg ha^{-1}) in soybean, which were significantly higher over control. Pancholi *et al*. (2017) reviewed that higher biological yield (56.78 q ha^{-1}), haulm yield (36.79 q ha^{-1}), pod yield (19.99 q ha^{-1}) and kernel yield (14.80 q ha^{-1}) was obtained in groundnut with application of 60 kg S/ha, which were significantly higher over other lower doses of sulphur. Saini *et al.* (2016) evaluated the effect of sulphur on groundnut in which they asserted that application of 30 kg S/ha significantly enhanced haulm yield (2830 kg/ha), pod yield (1830 kg/ha), kernel yield (1360 kg/ha) and shelling out percentage (73.9) over other lower levels of sulphur. Dutta *et al.* (2015) conducted a study at West Bengal and investigated that haulm yield (3420 kg/ha), pod yield (2070 kg/ha), kernel yield (1570 kg/ha) and shelling out percentage (75.9) were significantly increased with increasing levels of sulphur up to 30 kg/ha compared to other lower level of sulphur in groundnut. Noman *et al.* (2015) averred that application of 40 kg S/ha in groundnut produced highest number of pods per plant (19.4), haulm yield (3820 kg/ha), pod yield (2080 kg/ha) and shelling out percentage (71.9) compared to other lower doses of sulphur. Rana *et al*. (2015) reported that application of 75 kg S ha^{-1} significantly increased the head diameter (21.9 cm) and 1000 achene weight (50.6) compared to control in sunflower. Srivastava and Kumar (2015) found that application of 20 kg S ha^{-1} through single superphosphate produced significantly higher seed yield (2685 kg/ha) compared to control (2093 kg/ha) in castor. Veeranagappa *et al.* (2015) reckoned that RDF + FYM + 45 kg S ha^{-1} through gypsum produced highest number of pod (19.44 $plant^{-1}$), pod yield (13.58 q ha^{-1}), haulm yield (17.29 q ha^{-1}), oil content (45.57 %) and oil yield (618.80 kg ha^{-1}) which was significantly higher over control RDF + FYM by 12.9, 24.5, 37.4, 5.0 and 30.8 per cent, respectively in groundnut. Rao *et al.* (2013) conducted a study at Seethampeta andhra Pradesh and propounded that application of 45 kg S/ha in groundnut through gypsum gave highest haulm yield (1874 kg/ha), pod yield (1204 kg/ha), 100-pod weight (80.77 g), 100-kernel weight (40.78 g) and shelling out percentage (69.09) over other sulphur levels (15 kg and 30 kg/ha) and sources of sulphur (elemental sulphur and sulphur bentonite). Singh *et al.* (2013) found that seed yield, stover yield and oil content were increased by 18.7, 10.6 and 4.4% respectively, over control by the application of 20 kg S ha^{-1} in linseed. Dash *et al.* (2013) conducted an experiment at Odisha and averred that use of 20 kg S/ha in groundnut gave higher pod yield (18 q/ha), seed index (49.5 g) compared to other levels of sulphur whereas maximum haulm yield (30.6 q/ha) and shelling out percentage (72.6) were recorded with 40 kg S/ha. Pavani *et al.* (2012) reported that application of 30 kg S/ha in Sunflower produce maximum number of filled seeds per head (767), seed yield (2048 kg/ha) and stalk yield (4028 kg/ha) over control. Giri *et al.* (2011) conducted a field experiment in groundnut and avouched that application of 30 kg S/ha significantly increased kernel yield (3111 kg/ha) and seed index (38.24 g) followed by 15 kg S/ha, while lowest yield of kernel (1797 kg/ha) was obtained at control. Kumar *et al.* (2011) conducted a field experiment in sunflower and observed that application of 45 kg S ha^{-1} significantly increased head diameter (13.65 cm), seed weight (37.05 $head^{-1}$), test weight (44.24 g), seed yield (1.30 t ha^{-1}), stalk yield (4.83 t ha^{-1}), harvest index (22.28 %), oil content (40.63%), oil yield (529.9 kg ha^{-1}), which were significantly higher over 30, 15 and 0 kg S ha^{-1}. Patel *et al*. (2008) observed significantly higher haulm yield (58.57 q ha^{-1}), pod yield (36.99 q ha^{-1}), biological yield (95.56 q ha^{-1}), shelling out percentage (76) and seed index (38 g) when application of 40 kg S/ha was used in groundnut as compared to other lower doses of sulphur. Kumar and Yadav (2007) conducted an experiment in mustard and revealed that application of 45 kg S ha^{-1} produced higher number of seed (13.7 $siliqua^{-1}$), test weight (4.65 g), seed yield (2.00 t ha^{-1}), stover yield (5.34 t ha^{-1}) and oil content (39.18 %), which were significantly higher over control by 24.5, 18.6, 47.0, 3.5 and 9.0 per cent, respectively. Singh and Mann (2007) conducted an experiment at Rajasthan and averred that application of 40 kg S/ha produced maximum pod yield (2251 kg/ha) over 20 kg S/ha and control in groundnut. Singh and Singh (2007) carried out an experiment to know the relevant source and dose of sulphur in linseed and find out that application of gypsum and S dose @ 60 kg ha^{-1} yields higher seed, stover and oil yield during two year experimentation. Additionally, the application of 60 kg S ha^{-1} increased the oil yield by 36.7 and 36.2% over the control in first and second year, respectively. Venkatesh *et al.* (2006) conducted an experiment at Meghalaya in groundnut and purported that application of 40 kg S/ha through gypsum gave higher pod yield (28 q/ha), seed index (63 g) and shelling out percentage (70.5) of groundnut compared to 20 kg S/ha and control. On the basis of response equation, Rana *et al.* (2005) purported that progressive increase in P and S level enhanced yield attributes and seed yield, but the increase in seed yield was significant only up to 25 kg P_2O_5 ha^{-1} and 20 kg S ha^{-1}, Venkatesh *et al.* (2002) found that application of 30 kg S/ha through gypsum produced higher haulm yield (3810 kg/ha), pod yield (3098 kg/ha), seed index (57.20 g) and shelling out percentage (74.18) compared to 15 kg S/ha and control in groundnut. Sarkar and Banik (2002) reported that application of 50 kg S ha^{-1} produce maximum capsules per plant (45.88), capsule length (2.26 cm), seeds per capsule (45.55), 1000-seed weight (3.50 g) and seed yield (801 kg/ha) of sesame which were significantly higher over control. Data in tabular form in respect of yield and quality of different oilseed crops described in Table 2.

Effect of sulphur application on nutrient content and uptake

Yadav *et al*. (2021) asserted that N, P and K uptake (kg/ha) in groundnut significantly increased by 7.1, 23.1 and 10.5 per cent, respectively when RDF + 400 kg gypsum were used as compared to control. Yadav *et al*. (2020) examined that increasing the levels of sulphur up to 60 kg/ha progressively increased total uptake of N (117.31 kg/ha), P (15.50 kg/ha), K (107.55 kg/ha) and S (8.64 kg/ha), which were significantly higher over control by 120, 109, 99 and 95 per cent, respectively in groundnut. Kumar *et al.* (2020) conducted an experiment at Tamil Nadu and averred that application of RDF (17 kg N + 34 kg P_2O_5 + 54 kg K_2O/ha) + 40 kg S/ha through gypsum progressively increased uptake of N (101.43 kg ha^{-1}), P (23.45 kg ha^{-1}), K (74.50 kg ha^{-1}) and S (16.14 kg ha^{-1}) uptake in groundnut, which were significantly higher over control by 92.5, 150.8, 127.4 and 127.0 per cent, respectively. Patel and Zinzala (2018) from Gujarat adduced that increase in levels of sulphur up to 45 kg/ha significantly increased concentration and uptake of N, P, K and S in kernel and haulm of groundnut. However, Non-significant result was recorded between 30 and 45 kg S/ha. Saini and Jain (2017) purported that a successive increase in sulphur level up to 40 kg ha^{-1} considerably improved total N, P and S uptake in groundnut crop, whereas non significant variation was recorded between 40 and 60 kg S ha^{-1}. Kumar and Yadav (2007) conducted an experiment in mustard and propounded that application of 45 kg S ha^{-1} produced highest uptake of phosphorous (13.20 kg ha^{-1}), sulphur (25.50 kg ha^{-1}), which were statistically at par with application of 30 kg S ha^{-1} and significantly higher over 15 kg S ha^{-1} and control by 29.1, 10.5 and 53.5, 22.7 per cent, respectively. Kumar *et al*. (2008) anticipated that gradual increase in sulphur level up to 60 kg/ha significant increase in N, P, K and S uptake in groundnut crop, which were significantly higher over 0, 20 and 40 kg S/ha. Singh and Singh (2007) observed that application of S in linseed crop increased its content in seeds from 0.40% in the control to 0.49% with 60 kg S ha^{-1}. Also, the total uptake of N, P and S showed a significant linear increment on increasing S levels (0 to 60 kg/ha) from 69.0 to 101.1, 6.9 to 11.4 and 13.4 to 21.1 kg/ha respectively.

Effect of sulphur application on economics

Bhinda and Singh (2023) discerned that with increasing application of S from 0 to 40 kg ha^{-1} increases costs of cultivation (from Rs. 31,246 ha^{-1} to Rs. 33,264 ha^{-1}), gross returns (from Rs. 76,200 ha^{-1} to Rs. 91,372 ha^{-1}) net returns (from Rs. 45,000 ha^{-1} to Rs. 58,108 ha^{-1}) and B: C ratio (from 1.44 to 1.75) in ascending order. Application of 40 kg S ha^{-1} enhanced gross returns and net returns by 6.62%, 19.94% and 8.60%, 29.11% over 20 kg S ha^{-1} and 0 kg S ha^{-1}. B: C ratio was significantly increased by 21.5% under application of 40 kg S ha^{-1} (1.75) over 0 kg S ha^{-1} (1.44), but statistically at par with 20 kg S ha^{-1} (1.66). Singh *et al*. (2023) asserted that mustard fertilized with 40 kg S ha^{-1} fetched highest net monetary returns (Rs.79,920 ha^{-1}), while highest B: C ratio (2.8) found at 60 kg S ha^{-1} compared to other levels of sulphur. Devi *et al*. (2022b) investigated that the groundnut crop fertilized with 50 kg N + 40 kg S/ha fetched highest net returns (Rs. 1,34,307/ha), which were significantly higher over 30 kg N + 0 kg S/ha. The benefit cost ratio recorded with 50 kg N + 40 kg S/ha was 2.87, which was 57.7 per cent higher over 30 kg N + 0 kg S/ha. Dileep *et al*. (2021) stated that application of 40 kg S/ha fetched highest gross return (Rs. 1,30,763/ha), net return (Rs. 81,059/ha) and benefit cost ratio (1.63), which was significantly higher over 30 kg S/ha and 20 kg S/ha in groundnut. Krishna *et al*. (2020) found that maximum gross return (Rs. 96,333/ha), net return (Rs. 53,935/ha) and benefit cost ratio (1.27) in groundnut were obtained with sulphur dose 40 kg S ha^{-1} + NAA 50 ppm at 20 and 40 DAS, which was significantly higher over rest of the treatments. Kumar *et al*. (2019) reported that application of 45 kg S ha^{-1} in sesame fetched the highest gross returns (59186.15 Rs./ha) and net returns (30890.83 Rs./ha), which were significantly higher over control. Yadav *et al*. (2019) professed that the highest net return (Rs. 55,374 ha^{-1}) and benefit cost ratio (1.60) obtained at sulphur level 60 kg/ha in groundnut. However, further increase in Sulphur level up to 75 kg/ha non significantly increased economic returns but both these treatments gave significantly higher returns over 45, 30 and 15 kg S ha^{-1}. Nagar *et al*. (2017) asserted that the soybean fertilized with 60 kg S ha^{-1} fetched highest net returns (Rs. 30375 ha^{-1}) and B: C ratio (1.50) compared to other lower doses of sulphur. Saini *et al*. (2016) avouched that application of 40 kg S ha^{-1} fetched the highest net returns (Rs. 46,500 ha^{-1}) and benefit cost ratio (1.99), which were 64.8 and 20.6 percent higher over control respectively in groundnut. Dutta *et al*. (2015) asserted that the groundnut fertilized with 30 kg S ha^{-1} fetched highest gross return (Rs. 75,223), net returns (Rs. 48500 ha^{-1}) and B C ratio (2.41) compared to other lower doses of sulphur. Noman *et al*. (2015) reviewed that application of 40 kg S ha^{-1} fetched the highest net return (Rs. 46,400 ha^{-1}), with a B C ratio of 1.2, when compared to other sulphur levels in groundnut. Dash *et al*. (2013) examined that gross return (Rs. 68400 ha^{-1}), net return (Rs. 42500 ha^{-1}) and B C

Table 2: Effect of sulphur application on yield and quality parameters of oilseed crops.

Crops	Yield and quality parameters	Sulphur application (kg S ha^{-1})	References
Mustard	SY (1.84 t ha^{-1}), OC (40.1%)	40	Bhinda and Singh (2023)
Soybean	SY (1870 kg ha^{-1})	45	Manoj *et al*. (2023)
Mustard	SY (2.71 t ha^{-1})	60	Singh *et al*. (2023)
Sesame	SY (673 kg/ha), OC (41.5%)	40	Bhavana *et al*. (2022)
Mustard	SY (1.95 t ha^{-1})	60	Singh *et al*. (2022)
Sesame	SY (1.40 t ha^{-1})	45	Khan *et al*. (2021)
Sunflower	SY (1476.71 kg ha^{-1})	50	Indu and Singh (2020)
Sunflower	OC (41.65%)	60	Kalaiyarasan *et al*. (2020)
Groundnut	PC (23.89 %), OC (44.87%)	60	Yadav *et al*. (2020)
Sesame	SY (668.70 kg ha^{-1}), OC (46.87%)	45	Kumar *et al*. (2019)
Castor	SY (1670 kg ha^{-1})	60	Meena *et al*. (2019)
Sunflower	SY (1790 kg ha^{-1})	40	Perumal *et al*. (2019)
Groundnut	PC (24.30%), OC (44.61%)	75	Yadav *et al*. (2019)
Groundnut	PY (1903 kg ha^{-1})	75	Yadav *et al*. (2018)
Groundnut	PY (3365 kg ha^{-1})	40	Banu *et al*. (2017)
Soybean	PC (39.27%), OC (22.00%)	60	Nagar *et al*. (2017)
Groundnut	PY (1999 kg ha^{-1})	60	Pancholi *et al*. (2017)
Groundnut	PY (1830 kg ha^{-1})	30	Saini *et al*. (2016)
Groundnut	PY (2070 kg ha^{-1})	30	Dutta *et al*. (2015)
Castor	SY (2685 kg ha^{-1})	20	Srivastava and Kumar (2015)
Soybean	SY (1.70 t ha^{-1}), OC (20.2%)	40	Ram *et al*. (2014)
Sunflower	SY (2.66 t ha^{-1}), OC (42.7%)	40	Sheoran *et al*. (2013)
Safflower	SY (2.30 t ha^{-1}), OC (34.7%)	60	Singh and Singh (2013)
Sunflower	SY (2048 kg ha^{-1})	30	Pavani *et al*. (2012)
Sunflower	SY (1.30 t ha^{-1}), OC (40.63%)	45	Kumar *et al*. (2011)
Sunflower	SY (1.99 t ha^{-1})	50	Shekhawat and Shivay (2008)
Mustard	SY (2.00 t ha^{-1}), OC (39.18%)	45	Kumar and Yadav (2007)
Linseed	SY (1.89 t ha^{-1}), OY (827 kg ha^{-1})	60	Singh and Singh (2007)
Mustard	SY (22.3 q ha^{-1})	40	Rana *et al*. (2005)

OC- Oil content, OY- Oil yield, PC- Protein content, PY- Pod yield, SY- Seed yield.

ratio (2.64) were estimated higher with the application of 20 kg S ha^{-1}, followed by 40 kg S ha^{-1}, 60 kg S ha^{-1} and control in groundnut. Ramdevputra *et al*. (2010) reviewed that the application of 18.75 kg S ha^{-1} in groundnut resulted maximum gross return (Rs. 36,878), net return (Rs. 25,360) and benefit cost ratio of 2.20, which were significantly higher over other lower doses of sulphur. Kumar and Yadav (2007) stated that maximum net returns (Rs. 13,734/ha) and benefit cost ratio (1.18) in mustard obtained with the application of 45 kg S ha^{-1} and 30 kg S ha^{-1} respectively, which were significantly higher over 15 kg S ha^{-1} and control. Singh and Mann (2007) conducted a field experiment at Rajasthan and opined that the maximum B: C ratio was estimated with application of 40 kg S/ha compared to 0, 20 and 60 kg S/ha in groundnut. Singh and Singh (2007) studied the effect of levels of sulphur in linseed crop economics and asserted that net returns increased with the increases in S from 0 to 60 kg ha^{-1} from Rs. 8575 to 13948 and benefit : cost ratio with sulphur fertilization was recorded 1.75, 1.84 and 1.96 due to application of 20, 40 and 60 kg S/ha, respectively.

CONCLUSION

It is concluded that sulphur application in the range of 20-60 kg ha^{-1} substantially influences crop growth, yield, quality, nutrient uptake and the economic aspects of oilseed cultivation.

Conflict of interest

All authors declare that they have no conflicts of interest.

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