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Role of sulphur in cereal crops: A review

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Abstract
Sulphur (S) is an essential nutrient for all organisms. Sulphur is being categorized along with Nitrogen (N), phosphorous (P), and potassium (K) as the fourth macro nutrient. It is an important component for the production of proteins, and plays a part in chlorophyll synthesis. 41% of the Indian soils are known to be deficient in sulphur. Sulphur deficient soils are becoming common around the globe. Use of sulphur-free fertilizers is one of the main reasons behind sulphur shortage in soil. Higher crop yields may not be obtained when sulphur deficiency prevails as it affects the usage of applied N, P, and K by the crop. Many field experiments were conducted on different cereal crops from which it can be stated that 20-40 kg Sulphur/ha application significantly affected the growth, yield, nutrient uptake and economics. The goal of this review is to provide an update on recent findings related to these subjects, which may lead to a better understanding of S-fertilization and the role of S-fertilization in cereals.

Keywords: sulphur, cereals, growth and yield attributes, nutrient uptake, economics

Introduction
With an atomic number of 16, the atomic mass of 32.06 Sulphur is placed in group 16 and period 3 of the periodic table. Oxidation states of Sulphur are +4 in S02, +6 in H2SO4 and -2 in H2S (Rao, 1999) [27]. Due to its functions in a large variety of processes, Sulphur is an essential nutrient for all organisms (Kopriva *et al.*, 2015) [16]. The essential components of a well-fertilized crop are N,P and K but crop also needs sulphur (S) to attain yields and more nutritious foods. It is generally categorized under secondary nutrients but now it is gaining popularity as 4th macronutrient along with N,P and K (Jamal *et al.*, 2010. TSI, 2020) [12, 36]. In significant quantities, oil crops, legumes, forages and certain vegetable crops require sulphur. In certain crops, the amount of sulphur in the plant is identical to that of phosphorous.
Sulphur nutrition in the soil is affected by weathering, organic matter and activity of biota (Kumar, 2014) [17]. Due to frequent sulphur shortages in time and space, sulphur is considered as essentially important in all regions of the world (Khan *et al.*, 2006) [15]. More than 41% of the soils in India are deficient in Sulphur (Singh, 2001) [34]. Although the soil acted as a main source of sulphur supply to plants, recent day crops are not receiving sulphur sufficiently from the soil. Sulphur deficiency areas are becoming common across the globe (Irwin *et al.*, 2002) [11]. In many regions of the country, continued depletion of native reserves of S during the post-green revolution era has led to its deficiency (Dutta *et al.*, 2013) [14]. Reasons for sulphur deficiency in soil include increased fertilizer use, use of high-yielding crop varieties (Sinha *et al.*, 1995. Schrerer, 2001) [35, 32] and improved irrigation practises. Sulphur in general is not applied by farmers either via fertilizers or as a component of other fertilizers (Rao and Ganeshmurthy, 1994) [7]. On the other hand sulphur addition to the soil is also less due to increased use of high analysis sulphur-free fertilizers (Chaubey i, 1992) [4], decreased use of organic manures (Sakal and Singh, 1997) [29] and reduced use of sulphur fertilizers, sulphur-containing pesticides (Jamal *et al.*, 2010) [12]. Nitrogen remains the favoured chemical fertilizer, resulting in low primary crop productivity due to a lack of balanced and optimal nutrient application (Dutta *et al.*, 2013) [14]. Compared to many other fertilizers, sulphur-containing fertilizers cost a bit higher thus leading to its reduced usage by farmers (Dutta *et al.*, 2013) [14]. In the context of Indian agriculture, it is gaining considerable importance in the production of quality crops, particularly when there is increasing use of non-sulphur-containing fertilizers and less use of organic manure. The ratio of N: P2O5: K2O: S to 14.7:5.1:1.6:1 in India has been increased by the continuous use of S-free fertilizers (TSI, 2020). Sulphur is required in chlorophyll formation which enables photosynthesis via which starch, sugars, oils, fats, vitamins and other compounds generated by plants. Sulphur is an important constituent of amino acids like cysteine, cystine and methionine thus it plays an important role in formation of proteins.

(Jamal *et al.*, 2010) [12]. It is also a component of vitamins, co-factors and various secondary products (Leustek, 2000) [18]. Adequate sulphur is needed for oilseeds as it is involved in improving the quantity as well as the quality of the oil. Sulphur is not only responsible for enhancing nutritional value but also crop growth (Zhao *et al.,* 2001) [43]. Regarding crop quality sulphur increases the cereal quality for milling and baking, the marketability of dry coconut kernels (copra), the quality of tobacco, the nutritional value of forages, etc. It is involved in the activation of enzymes thus aiding biochemical reactions in the plant (TSI, 2020).

Wheat, paddy, sorghum, millet, barley and maize constitute the important cereals. Cereals belong to Gramineae family. Cereals are grown in large quantities; they provide more nutrition, used as a staple food in most developing countries. Compared to most other crops cereals give the highest yield. They are rich sources of protein, iron, vitamin b complex, carbohydrates, niacin, riboflavin, thiamine, fibre, vitamin E and traces of minerals (Yasmin**,** 2017) [42]. According to the Indian Ministry of Agriculture's final estimate for the year 2015-16, the production of major cereals such as rice, maize and bajra was 104.32 million tonnes, 21.8 million tonnes and 8.08 million tonnes, respectively. 272 million metric tons of cereals are estimated to be produced in India in the fiscal year 2020. India is not only the largest cereal producer but also the world's largest exporter of cereal products. The major paddy growing states are West Bengal, Uttar Pradesh (U.P) and Punjab. Major wheat-growing areas are U.P, Punjab, and Haryana. Major maize growing areas are Karnataka, Madhya Pradesh, Bihar**.** Gujarat, Madhya Pradesh, Haryana are the top millet producing states.

Among these states maximum of them are known to be sulphur deficient. For example considering Punjab alone which is one of the largest paddy and wheat growing area in India, 6 out of 22 districts have more than 20% soils deficient in sulphur. In India, the removal of S from crops amounts to approximately 1.26 million tonnes (Mt), while its fertilizer replenishment is just approximately 0.76 Mt (Tiwari and Gupta, 2006) [38]. Participatory surveys conducted in the Indo-Gangetic Plain (IGP) showed that a rice-wheat system yielding, on average, 3.92 tonnes/ha of rice and 3.95 tonnes/ha of wheat each year eliminates approximately 331.0 thousand tonnes of S annually, although its application is largely ignored (Sharma *et al.*, 2003) [33]. According to a report by the Sulphur Institute (TSI, 2020), 68 million hectares of cultivated land or 40 percent of arable land in India suffer from extreme sulphur deficiency, causing soil health to deteriorate. In India, a total of 2.3 million tonnes of sulphur should be used to address the soil health imbalance, but in actual practice, only 0.7 million tonnes of sulphur are used per year, There is, therefore, a difference of 1.6 million tonnes (Morris, 2006) [20]. The ratio of the application of nitrogen, phosphate, potassium and sulphur to the soil in India is 16.1:6.6:1:1, while it should preferably be 4:2:1:1:1 (Morris, 2006) [20].

Range of Sulphur required for the production of one ton of seeds is about 1-6 kg for cereals, 5-13 kg for legumes and 5-20 kg for oilseed crops. S deficiency can lead to a significant reduction in cereal yield by as much as 50 percent **(**Zhao *et al.***,** 2001) [43]. Sulphur deficiency in the soil allows toxic nitrates and arnides to accumulate, which retards protein formation and also decreases the quality of protein in both grain and straw (Gupta and Schnug, 2001) [8]. Sulphur deficiency leads to decreased use efficiency, economic use of applied NPK fertilizers and sustained yield may not be obtained **(**Khan *et al.*, 2006) [15]. The use of high levels of other nutrients (N, P and K) in sulphur deficient soil does not result in increased yields due to imbalances in the N / S and P / S ratios in plants. Its deficiency is currently one of the key constraints on the sustainable growth and productivity of a number of field crops. With the projected rise in global food demand, demand for S and other plant nutrients is further expected to increase (Tilman *et al.*, 2011) [6]. Keeping in the view the importance of sulphur nutrition in crop physiology and economic yield this review is written to reiterate the importance of the sulphur application.

Sulphur deficiency symptoms in crops:

Sulphur deficiency results in pale yellow or light green colouration of leaves. Symptoms of sulphur deficiency and nitrogen deficiency are in many ways similar. Sulphur deficiency in cereals affects the maturity i.e., delaying their maturity.

Rice- Leaf sheath and leaf blade develop yellow colouration. Crop becomes stunted and reduced number of panicles is produced when compared to normal plants.

Maize- Younger leaves show yellowing in between the veins. If the deficiency continues to final stages leaf margins, the base of the stem develops reddish colouration.

Wheat- Under severe deficiency yellowing of the whole plant can be observed. Yellowing between the veins is also a symptom.

Sorghum- In initial deficiency stages younger leaves turn pale green while severe deficiency turns older leaves along with younger leaves to pale green.

Detecting sulphur deficiency:

In soil: For detecting available sulphur in soil many numbers of chemical methods are available. The important point is that the method selected for determination should be accurate and it should be correlated with crop response to the sulphur application. 0.15% $CaCl_2$ solution is used for the extraction of soil sulphur in India. Less than 10 ppm available sulphur in soil is considered to be deficient (Williams and Stainbergs, 1959) [41].

In plant: Standard analytical methods are followed for sulphur analysis in plant tissue. Generally plant sample is digested by using wet digestion method which involves HNO_3 and $HClO_4$ (Chaudary and Cornfield, 1966) [5]. Cereal tissue samples after testing if they are determined to contain sulphur less than 0.2 % then sulphur as a fertilizer is recommended to be applied.

Role of Sulphur in cereal crops:

A) Effect of sulphur on growth and yield attributes of cereals:

Naw Mar Lar *et al.* (2007) [22], noted that yield attributes like plant height (102.6 cm), effective tillers/hill (7.3), panicle length (27.7 cm), 1000 grain weight (24.44 g) of aromatic rice were better with 60 Kg S/ha application when compared to preceding levels. Sandeep Singh *et al.* (2016) [31] experimented on pearl millet and found out that application of 30 kg S/ha increased the plant height (224.7 cm), ear head length (29.1 cm), ear head diameter (10.85 cm), and test weight (11 g) when compared to control (204.2cm, 25.1 cm, 8.93cm, 9.75 g). Jeet *et al.* (2014) [28] experimented on quality protein maize and reported that application of 45 kg S/ha significantly improved number of green leaf/plant (8.92 9.80), dry matter (240.03 245.64 g), cobs/plant (1.29 1.32), cob diameter (1.29 1.32 cm) and test weight (232.85 236.06 g) when compared to other levels. Bharathi and Poongothai (2008) [3] based on their experiment on maize reported that 30 kg S/ha application improved leaf length (71.2 cm), grain yield (7271 kg/ha) and harvest index (33.34) when compared to other levels. Kumbari and Kubsad (2019) [24] found out that application of 30 kg S/ha in sorghum resulted in improving plant height (224.89 cm), ear weight (163.07 g/plant), grain weight (125.69 g/plant), ear length (21.41 cm) and test weight (2.84 g) when compared to other levels**.** Sandeep Singh (2017**)** [30] stated that application of 30 kg S/ha resulted in a significant response of pearl millet yield attributes like plant height (226.5 cm), ear head length (30.1 cm), ear head diameter (10.9 cm), test weight (11.08 g) and grain weight/ear (34.12 g). Thirupathi *et al.* (2016) concluded that growth parameters of Maize like plant height (180 cm), dry matter (234.7 g/plant) and leaf area index (3) were significantly affected up to 60 kg S/ha application. Pavithra *et al.* (2018) [23] experimented on quality protein maize, reported that 45 kg S/ha application significantly improved plant height (162.9 cm), leaf area index (1.83) and dry matter production (8117) when compared to control (151.3 cm, 1.54, 6657 kg/ha). Navatha *et al.* (2017) [21] based on the experiment conducted on maize concluded that 40 kg S/ha significantly improved plant height (194.4 cm), LAI (3.66) and dry matter production (12218 kg/ha) when compared to control (166.4 cm, 3.06, 10675 kg/ha). Bentonite as a source of sulphur application in Sorghum resulted in maximum plant height (224.56), ear weight (212.87 g/plant), grain weight (127.79 g/plant), ear length (21.31 cm) and test weight (2.85 g) when compared to other sources of sulphur (Kumbari and Kubsad, 2019**)** [24]. Growth, yield attributes of Rice like plant height (102.25 cm), number of tillers/hill (15.325), dry matter production (11916 kg/ha), number of panicles/m2 (255.13) and number of grains/panicle (122.44) improved by the application of 45 kg S/ha (Jawahar and Vayaipuri, 2010) [13]. Rahman *et al.* (2007) [25] based on their experiment on Boro rice, reported that 20 kg S/ha application affected the plant height (94.93 cm), No. of effective tillers/hill (12.15), Panicle length (25.25 cm), Filled grains/panicle (153.15 cm), and 1000 grain weight (24.71 g). Plant height (105.13 cm), Leaf area index (4.48) and dry matter accumulation (963.39 g/m2) from 90 DAS to harvest in rice were of maximum value due to application of 45 kg S/ha as noted by Vikas *et al.* (2017) [40].

Naw Mar Lar *et al.* (2007) [22], reported that application of 60 kg S/ha in aromatic rice gave highest grain yield (5.54 tons/ha), straw yield (13.64 tons/ha), biological yield (19.17 tons/ha) when compared to control (5.09, 10.26, 15.36 tons/ha). Asha ram *et al.* (2016) [2], reported that effective tillers/m2 in rice was significantly influenced up to 30 kg S/ha. Rakesh Kumar *et al.* (2014) [26] in his experiment on rice noted that application of 10-30 kg S/ha increased the grain yield from 2.52 to 2.92 t/ha, application of phosphogypsum (3.09), SSP (2.93) increased the grain yield. Harvendra Singh and Harendra Singh (2014) [10] experimented for two years on pearl millet from which they reported that application of 40 kg S/ha resulted in maximum grain yield (23.08, 22.96 q/ha) and stover yield (55.81,55.47 q/ha) over control. Asha ram *et al.* (2016) [2] noted that irrespective of the sources applied (gypsum, phosphogypsum) to aerobic rice maximum panicle weight (2.19 g) was obtained due to application of 60 kg S/ha and also stated that gypsum application @ 60 kg S/ha resulted in highest grain/panicle (130). Sandeep Singh (2017) [30] stated that 30 kg S/ha resulted in maximising grain yield (3.43 t/ha) and stover yield (8.34 t/ha) of pearl millet when compared to control. Asha ram *et al.* (2016) [2] stated that the application of gypsum @60 kg S/ha in rice increased the grain yield from 4.01 tonnes/ha (control) to 4.47 tonnes/ha. Jeet *et al.* (2014) [28] based on his experiment on maize for two years stated that grain yield (6.27 6.34 tonnes/ha) and biological yield (16.10 16.48) significantly improved due to application of 45 kg S/ha. Anil *et al.* (2012) [1] reported that 30 kg S/ha application in rice was beneficial in improving yield attributes like panicle/m2 (303.6), grains/panicle (204.9), grain yield (7.44 t/ha), harvest index (0.42) and 1000 seed weight (15.9 g) when compared to control (271.4, 191.8 g, 7.23 t/ha, 0.41, 15.9 g). In an experiment conducted by Asha ram *et al.* (2016) [2] on wheat, application of 30 kg S/ha resulted in maximum effective tiller/m2 (304), spike weight (1.84 g) and the number of filled grains/spike (47.1) over control (299, 1.76 g, 44.7). Thirupathi *et al.* (2016) [37] also noted that 60 kg S/ha maximized the yield attributes like grain and stover yield in maize. Vikas *et al.* (2017) [40] based on their experiment on rice revealed that yield and yield attributes like number of shoots (365.87 /m2), length of panicle (25.92 cm), number of grains/ panicle (192.93), test weight (23.10 g), grain yield (43.19 q/ha), straw yield (56.54 q/ha) and harvest index (43.29 %) were efficient under application of 45 kg S/ha**.** Sandeep Singh *et al.* (2016) [31] concluded that grain yield (3.31 t/ha) and stover yield (8.05 t/ha) increased up to 30 kg S/ha in pearl millet whereas the grain yield and stover yield in control were 2.69 t/ha and 6.78 t/ha. Bharathi and Poongothai (2008) [3] stated that 45 kg S/ha significantly influenced the length of cob (16.7 cm), 100-grain weight (32.4 g) and straw yield (14562 kg/ha) in maize. Harvendra Singh and Harendra Singh (2013) [9] stated that 25 kg S/ha application showed a significant effect on wheat grain (46 q/ha) and straw yield (66.8 q/ha) when compared to other levels. Grain yield ranged from 2997 to 3679 kg/ha and stover yield ranged from 3390 to 4029 kg/ha due to 45 kg S/ha application in maize crop (Pavithra *et al.*, 2018) [23]. Days to 50% tasselling (55.8) and days to 50% silking (59.1) were influenced by 40 kg/ha sulphur application on maize **(**Navatha *et al.*, 2017) [21]. Manoj and Mranalini (2016) [19] experimented on Barley, revealed that application of 40 kg S/ha improved the ear length (17.97 cm), grain yield (58.02 q/ha) and straw yield (137.12 q/ha) over control (15.85 cm, 50.11 q/ha, 116.79 q/ha). Yield parameters of sorghum like grain yield, dry fodder yield and harvest index improved via application of 30 kg S/ha (44.91 q/ha, 9.29 t/ha, 0.48) as a level and bentonite as a source (44.67 q/ha, 9.06 t/ha, 0.49) as said by Kumbari and Kubsad (2019) [24]. Jawahar and Vayaipuri (2010) [13] also stated that application of 45 kg S/ha significantly affected grain yield (5855.33 kg/ha) and straw yield (9475.33 kg/ha) of rice when compared to control (4595.94, 7543.46 kg/ha). Grain yield (5.81 t/ha), straw yield (7.38 t/ha) and biological yield (13.19 t/ha) significantly increased up to 20 kg S/ha in rice as concluded by Rahman *et al.* (2007) [25]. Tripathi and Ravindra (2013) [39] revealed that yield components of rice like productive tillers/m2 (320, 331), number of filled grains/panicle (138 171), test weight (36.1 40.8 g) and dry matter accumulation (672, 684 g/m2) were significantly affected during the experiment conducted for two consecutive years. Harvendra Singh and Harendra Singh (2014) [10] stated that the application of ammonium sulphate resulted in maximum grain (22.15, 22.21 q/ha) and stover yield (54.29, 54.18 q/ha) when compared to other sources**.** Asha ram ***et al.*** stated that applying 30 kg S/ha resulted in maximum yield whereas significant yield was reported only up to 15 kg S/ha.

B) Effect of sulphur on quality of cereals

Rakesh Kumar *et al.* revealed that 40 kg S/ha application in rice gave the highest protein yield (234 kg/ha) and also stated that phosphogypsum application as a source resulted in highest protein yield (207 kg/ha). Application of ammonium sulphate in pearl millet proved to be best in giving maximum protein content (10.4, 10.6%), protein yield (230.4, 235.4 kg/ha) but it was at par with gypsum application **(**Harvendra Singh and Harendra Singh, 2014) [10]. Application of 45 kg S/ha resulted in maximum protein content in grain (10.6%) of pearl millet, when compared to control (10%, 273.8 kg/ha), whereas protein yield (360.5 kg/ha) was maximum in 30 kg S/ha application (Sandeep Singh, 2017) [30]. Thirupathi *et al.* (2016) [37] revealed that crude protein content in maize increased by 18.1% over control due to the application of 60 kg S/ha. Quality parameters of barley like protein content (12.3), protein yield (722) and starch content (53.8) were improved due to the application of 40 kg S/ha application (Manoj and Mranalini, 2016) [19]. Crude protein of 8.31% was obtained in sorghum due to usage of Bentonite as a sulphur source and crude protein of 8.34% was obtained due to 30 kg S/ha application which was noted by Kumbari and Kubsad (2019) [24] in their experiment on sorghum. Protein content of 10.8 % was recorded in pearl millet grain due to application of 60 kg S/ha and protein yield of 351 kg/ha was noted due to application of 30 kg S/ha (Sandeep Singh *et al.*, 2016) [31].

C) Effect of sulphur on nutrient uptake by cereals

Naw Mar Lar *et al.* (2007) [22], revealed that sulphur application of 20 kg/ha in rice gave significant results of N uptake over the control and it was at par with other levels and the percentage of N uptake was 12, 13.5 and 17.2 % for 20, 40 and 60 kg S/ha when compared with the control. Harvendra Singh and Harendra Singh (2013) [9] based on their experiment on the wheat crop for two consecutive years revealed that sulphur applied @ 25 kg/ha significantly influenced the N (140.4 134.3), P (19.3 19.6) and K (29.8 29.3) uptake. Asha ram *et al.* concluded that application of phosphogypsum @ 30 Kg S/ha in rice resulted in good crop recovery of Sulphur and also stated that recovery of 22.9% was noted in wheat with the application of 15 kg S/ha. In an experiment conducted by Naw Mar Lar *et al.* (2007) [22] it was noted that S application in rice significantly influenced K uptake, the maximum uptake of K in grain (26.6 kg/ha) and straw (88.4 kg/ha) were reported due to the application of 60 kg S/ha. Rakesh Kumar *et al.* (2014) [26] reported that among the different sources applied in rice phosphogypsum (grain-8.66 kg/ha, straw-7.31 kg/ha) was at par with gypsum (grain-7.58 kg/ha, straw-6.47 kg/ha) than that of pyrites (grain-6.23 kg/ha, straw-4.71 kg/ha) and among the levels applied 30 kg S/ha resulted in maximum S uptake by grain (8.76) and straw (14.57) in rice. Application of 60 kg S/ha and ammonium sulphate as a source in pearl millet were responsible for maximum N and P availability in the soil after harvest (Harvendra Singh and Harendra Singh**,** 2014) [10]. Sandeep Singh (2017) [30] revealed that uptake of N (grain-57.2 kg/ha, stover-45.8 kg/ha), P (grain-8.3 kg/ha, straw-10.8 kg/ha), K (grain-19.8 kg/ha, straw-170 kg/ha) in grain and straw of pearl millet was highest due to application of 30 kg S/ha whereas the sulphur (grain-8.9 kg/ha, straw-13.7 kg/ha) uptake was highest in 60 kg S/ha application. 40 kg S/ha application in barley significantly affected the organic carbon (4.2 g/kg), available N (146.2 kg/ha), available P (9.4 kg/ha) and available K (120.5 kg/ha) of soil which was beneficial to the following crop (Manoj and Mranalini, 2016) [19]. P uptake by grain (8.1 kg/ha) and straw (6.4 kg/ha) of rice was significantly influenced by the Sulphur application of 20 Kg S/ha, whereas the maximum uptake of P in grain (8.4 kg/ha) and straw (6.7 kg/ha) was seen due to application of 60 kg S/ha (Naw Mar Lar *et al.***,** 2007) [22]. Soil status like organic carbon (5.18 g/kg), available N (264.7 kg/ha), available P (17.2 kg/ha) and available S (14.3 mg/kg) were noteworthy under 25 kg S/ha application in the Wheat crop as reported by Harvendra Singh and Harendra Singh (2013) [9]. N, P and K concentrations of 1.23, 0.52, 0.83% were reported in grains of rice due to the application of 40 kg S/ha (Anil *et al.***,** 2012) [1]. Bharathi and Poongothai (2008) [3] stated that increasing levels of sulphur had an impact on the uptake of N by maize grain (69.4 to 92.6 kg/ha) and straw (9.59 to 10.8 kg/ha), P uptake ranged from 22.3 to 34.6 kg/ha by grain and 32.9 to 36 kg/ha by straw and K uptake ranged from 43.5 to 74.2 kg/ha by grain and 171.3 to 180.3 kg/ha by straw. Nutrient uptake of grain and straw by barley was 115.6, 76.4 kg/ha for N, 13.4, 17.0 kg/ha for P, 29.3, 267.7 kg/ha for K, 14.8, 20.1 kg/ha for S and 139.4, 245.8 g/ha for Zinc (Zn) due to 40 kg S/ha application (Manoj and Mranalini, 2016) [19]. N (119.0,125.4 kg/ha and 39.0, 46.6 kg/ha) and S (29.5, 30.2 kg/ha and 21.4, 21.9 kg/ha) uptake by grain and straw of rice were significantly impacted during two consecutive years due to application of 60 kg S/ha as reported by Tripathi and Ravindra (2013) [39]. Harvendra Singh and Harendra Singh (2014) [10] revealed that uptake of N (76.5 76.9 kg/ha) and P (12.3 12.6 kg/ha) by pearl millet was highest with the application of ammonium phosphate whereas S uptake was highest by application of Gypsum (15.6 16.2 kg/ha) and also stated that 40 kg S/ha resulted in maximum N (77.8 80.5) and P (13.1 13.8) uptake whereas S uptake (16.8 17.4 kg/ha) was highest @ 60 kg S/ha application. Sulphur application @ 30 kg/ha significantly influenced the N (55.6, 45.0 kg/ha), P (8.3, 10.4 kg/ha), K (19.5, 165 kg/ha) and Zn (76.8 239.8 kg/ha) uptake by grain and straw of pearl millet **(**Sandeep Singh**,** 2016) [31].

D) Effect of sulphur on economics of cereals-

Gypsum application @ 60 kg S/ha in aerobic rice resulted in highest gross returns (₹149800 and ₹174100) and B: C ratio (1.94 and 2.14) during 2010-2011, 2011-12 as stated by Asha ram *et al.* (2016) [2]. Irrespective of the sources, application of 15 kg S/ha resulted in highest B: C ratio (1.94 and 2.14) in wheat crop. Rakesh Kumar *et al.* (2014) [26] in his experiment on rice reported that sulphur application @ 30 kg S/ha gave highest agronomic efficiency and apparent S recovery. In an experiment conducted by Sandeep Singh *et al.* (2016) [31] on pearl millet-lentil crop sequence, it was stated that application of 45 kg S/ha grabbed the highest net returns (₹ 63 922 /ha) and B: C ratio (3.78). Jeet *et al.* (2014) [28] concluded that highest net returns (₹ 37139.20/ha and ₹ 38 013.15/ha) and B: C (2.22 and 2.27) ratio were obtained in maize by application of 45 kg S/ha**.** Kumbari and Kubsad (2019) [24] reported that application of Bentonite @ 30 kg/ha in sorghum efficiently improved gross returns (92.81 ₹× 103/ha), net returns (49.31 ₹× 103/ha) and B: C ratio (2.13). Net income increased from ₹ 3338 (0 kg S/ha) to ₹ 15883 (20 kg S/ha) as reported by Rahman *et al.* (2007) [25] based on his readings on Boro rice.

Conclusion:
Sulphur along with N, P and K is considered as the fourth major plant nutrient. Sulphur being a component of cystine, cysteine and methionine is essential for protein synthesis in crops. The removal of S from crops amounts to approximately 1.26 million tonnes (Mt), while its fertilizer replenishment is just approximately 0.76 Mt. Sulphur deficiency affects the efficiency of applied N, P, K resulting in poor economics of cereals. Proper management of sulphur is the only way to make Indian soils jump out of the deficiency. The use of Sulphur not only helps to maintain high yields but also increases the efficiency and quality of cereal production. High yield with a good quality of cereals is only possible when there is a balanced nutrient dosage thus sulphur as a source must be given to the crop in one or the other way. From the different experiments conducted it can be stated that 20-40 kg S/ha application maximized the benefits in cereals. Sources of sulphur like SSP, gypsum, ammonium phosphate and phosphogypsum supply sulphur along with one primary plant nutrient thus reducing the impact of the price of fertilizers.

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