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Effect of sulphur nutrition on growth parameters, yield parameters, yield, nutrient uptake, quality and economics of maize: A review

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Abstract
Maize, queen of cereals is a nutrient exhaustive crop and sensitive to sulphur deficiency. Sulphur deficiency in corn results in interveinal chlorosis, yellowing of younger leaves, reddening of stems and leaves. Sulphur is the fourth major plant nutrient next to nitrogen, phosphorus and potassium. It plays a prominent role in formation of chlorophyll, proteins, oil synthesis and biosynthesis of proteins. Sulphur has significant role in growth parameters, yield attributes and yield of maize crop. The uptake of primary nutrients and efficiency of applied fertilizers were seriously influenced by sulphur availability. Sustaining higher yield is not possible under sulphur deficiency. The investigations carried out by eminent research scientist in maize has shown positive impact and application of 45 to 60 kg ha^{-1} of sulphur gave maximum growth, yield attributes, nutrient uptake, yield and quality parameters. The present paper is a panoramic view of sulphur nutrition in maize from results of different researchers.

Keywords: Effect of sulphur nutrition on growth parameters, different researchers, phosphorus and potassium

Introduction
Maize is a miracle crop which is called as queen of cereals due to its high yield potential among the various cereal crops. In India it ranks third next to rice and wheat among cereal crops owing to its multipurpose needs. The adoptability of maize to different agro-climatic conditions and adverse conditions makes it versatile in nature. Maize serves as food, feed for humans and animals as well as raw material for industries such as protein, starch, oil, pharma, food sweeteners, alcoholic beverages, cosmetics, bio-fuel etc. The productivity of maize in India is (2583 kg ha^{-1}) which is lower comparing with other countries (5160 kg ha^{-1}) due to various reasons, among which nutrient management plays a crucial role. Sulphur is the fourth major nutrient element after primary nutrients for plant growth and development. Generally cereals require low sulphur but have higher yield potential. The uptake of sulphur by cereals per unit area is equal to oilseeds due to higher productivity of cereals although the sulphur requirement for producing a ton of cereals is low**.** Sulphur deficiency was found to be widespread due to lack of organic manure addition, high intensive cropping, leaching, erosion and use of high analysis sulphur lack fertilizers. Sulphur deficiency is widespread in Indian soils accounting to 40-45% of districts covering 57-64 million ha of net sown area. The full yield potential cannot be achieved without sulphur although other nutrients are sufficient for maize. Saalbach (1973) [42] reported 10% to 30% yield loss due to sulphur deficiency in maize and 35% by Pal and Singh (1992) [33]. Yellowing of newly developed or younger leaves is the characteristics of sulphur deficiency in corn. Interveinal chlorosis, reddening of stems and leaves initially from edges of leaf then gradually to midrib are the specific symptoms, in addition the older leaves remains greenish Tiwari *et al.*, (2006) [55]. Maize responds positively to sulphur application and removes around 30 to 70 kg ha^{-1} Sarfaraz *et al.*, (2014) [46]. Sulphur enhances crop quality owing to its direct effect on plant biochemical reactions and being a part in formation of chlorophyll. Sulphur containing amino acids lack were the main factor responsible for decreasing the biological value of proteins Singh (2008) [8, 13, 14, 18, 20, 25, 32, 39, 43, 48, 51, 53]. The uptake of other major nutrients have also been significantly influenced by sulphur application from research evidences Bharathi and Poongothai (2008) [6].

Effect of sulphur nutrition on growth parameters of maize
Sinha *et al.*, (1995) [43, 52] found that sulphur application at 45 kg ha^{-1} gave significant increase in plant height and dry matter production in maize crop.

Dhananjaya (1998) [10, 11] found that plant height increased with increasing levels of sulphur application up to 45 kg ha^{-1}. Baktash (2000) [4] revealed that best results were obtained with 60 kg S ha^{-1} for plant height. Pandey *et al.,* (2002) [1, 33] noticed that sulphur application at 20 mg kg^{-1} soil gave maximum increase in dry matter yield of maize crop from his study. Dhananjaya and Basavaraj (2002) [10, 11] documented that application of sulphur at 45 kg ha^{-1} increased the plant height compared to no application. Ram *et al.*, (2003) [38, 39, 51] registered significant increase in plant height with application of sulphur at 60 kg ha. Maurya *et al.*, (2005) [25] observed a significant increase in growth parameters such as height of the plant, no. of green leaves plant, leaf area index and dry weight with increasing levels of sulphur application in the range of 0 to 60 kg ha^{-1}. Sankaran *et al.*, (2005) [45] concluded that sulphur application enhanced the growth attributes significantly compared to control. Khan *et al.*, (2006) [16, 19] documented higher fresh matter yield and dry matter which is 41% and 55% higher than control treatment by sulphur application at 60 kg ha^{-1} through gypsum from his experimental study. Bhagyalakshmi *et al.*, (2010) [5] documented significant increase in plant height of maize with application of 60 kg S ha^{-1} over control. Gahlout *et al.,* (2010) [14] documented tallest plants with sulphur fertilization at 45 kg S ha^{-1} while compared to no application in maize. Srinivasarao *et al.*, (2010) [53] concluded that plant height and dry matter production was maximum with application of sulphur at 20 kg ha^{-1} than control. Rahman *et al.,* (2011) [36] divulged that dry matter production increased with application of elemental sulphur 5 t ha^{-1} from his study. Jeet *et al.,* (2012) [18] observed a significant increase in plant height, number of green leaves plant^{-1}, LAI and dry matter plant^{-1} with sulphur application at 45 kg S ha^{-1} in maize. Choudhary *et al.*, (2013) [8] concluded that application off sulphur at 40 kg ha gave higher plant height at harvest stage (291cm) than control treatment in two crops. Nanthakumar *et al*., (2014) [27] found that plant height was maximum (170.7cm) with application of 80 kg S ha than lower levels and control treatment in maize from his study. Ogunsola and Adetunji (2015) [30] registered a significant increase in dry matter production of maize with application of sulphur at 10 or 20 kg ha^{-1} compared to control in maize. Tirupathi *et al*., (2016) [54] concluded that application of sulphur at 60 kg ha^{-1} significantly increased the growth parameters such as leaf area index (3.0), plant height (180 cm), and dry matter (234.7 g plant^{-1}) and increasing levels up to 80 kg ha^{-1} remained statistically on par. Padma *et al.,* (2018) [31] found a significant increase in growth parameters *viz*., plant height, leaf area index and dry matter production with application of 60 kg sulphur ha^{-1} over control and remained on par with 40 kg ha^{-1} of sulphur application in maize.

Effect of sulphur application on yield parameters and yield of maize

Das *et al*., (1975) [9, 34] found that sulphur application at 30 kg ha^{-1} increased grain yield of maize by 9% from his study. Rahul (1975) [37] concluded that application of sulphur at 90 kg ha^{-1} gave maximum yield in maize compared to control. Singh *et al.,* (1987) [8, 13, 14, 18, 20, 25, 32, 39, 43, 48, 51, 53] registered a significant increase in maize yield with application of sulphur at 22.4 kg ha^{-1} significantly increased the maize yield of maize up to 43.4% over control. Leary and Rehm (1990) [21] reported that sulphur application at 10 kg ha^{-1} gave higher yield than lower and higher levels from his study. Ojeniyi and Kayode (1993) [29] revealed that application of sulphur at 80 kg ha^{-1} gave maximum cob weight compared to lower levels from his study. Sinha *et al.,* (1995) [43, 52] stated that application of sulphur gave significant increase in number of rows cob^{-1}, cobs plant^{-1}, cob and grain weight of maize. Dhananjaya (1998) [10, 11] observed a significant increase in cob number plant^{-1}, grain yield and stover yield with application of 45 kg of sulphur ha^{-1} in maize crop. Baktash (2000) [4] found a significant increase in length of cob, cobs plant^{-1} and grains cob^{-1} with application of 60 kg sulphur ha^{-1} in maize. Sakal *et al.,* (2000) [43, 52] observed a significant increase in grain yield with sulphur application at 40 kg ha^{-1} in maize. Toatia *et al.*, (2000) [56] found a significant increase in stover yield with sulphur application at 80 kg ha^{-1}. Grain yield of maize was significantly higher with application of sulphur at 5-10 kg ha^{-1} Weil and Mughogho (2000) [41]. Application of sulphur at 60 kg ha^{-1} gave significant increase in yield attributes like cobs plant^{-1}, rows cob^{-1}, cob weight and grain weight cob^{-1} than higher levels in maize Singh (2001) [8, 13, 14, 18, 20, 25, 32, 39, 43, 48, 51, 53]. Majumdar *et al.*, (2002) [22, 23] found that yield of maize increased with 20 kg application of sulphur ha^{-1}. Application of sulphur at 45 kg ha^{-1} significantly improved the yield parameters such as length of cob, cob girth and weight of grains cob^{-1} in maize Dhananjaya and Basavaraj (2002) [10, 11]. Alam and Islam (2003) [2] divulged that application of sulphur at 20 kg ha^{-1} significantly gave maximum grain yield. Ram *et al.,* (2003) [38, 39, 51] found that yield was higher with application of 20 kg sulphur ha^{-1}in maize. Biswas *et al.,* (2004) [7, 34] concluded that maize yield increased from 11 to 93% with application of sulphur from the range of 30 to 45 kg ha^{-1}. Rasheed *et al.,* (2004) [40] observed a significant increase in yield components like grain cob^{-1} and grain weight cob^{-1} with sulphur application at 20 kg ha^{-1}.Yield attributes such as cobs plant, individual cob weight and weight of grains, grain yield and stover yield of maize were significantly higher than control treatment with application of 60 kg sulphur ha^{-1} Mehta *et al.*, (2005) [26, 56]. Maurya *et al.,* (2005) [25] documented a significant increase in yield attributes with 45 kg ha^{-1} of sulphur application than control. Khan *et al*., (2006) [16, 19] documented significant increase in test weight and stover yield of maize with 60 kg ha^{-1} of sulphur application and it remained on par with 40 kg ha^{-1} of sulphur application. Adhikary and Pandey (2007) [1, 33] concluded that application of sulphur at 20 kg ha^{-1} gave maximum grain yield compared to higher and lower levels in maize and 63.4% increase than control treatment. Grain and stover yield significantly increased with application of 60 kg ha^{-1} of sulphur application in maize crop Singh (2008) [8, 13, 14, 18, 20, 25, 32, 39, 43, 48, 51, 53]. Grain yield of maize was higher with application of 30 kg sulphur ha^{-1} Manjunathaiah *et al.,* (2008) [24]. Bharati and Poongothai (2008) [6] registered significant increase in test weight of grains and 16.85% of yield compared to control treatment with sulphur application at 45kg ha^{-1} of maize. Bhagyalaxmi *et al.*, (2010) reported sulphur application at 60 kg ha^{-1} gave maximum cob length, test weight, grain yield and stover yield of maize. Gahlout *et al*., (2010) [14] concluded that sulphur application at 45 kg ha^{-1} gave an significant increase in more no. of grains cob^{-1}, test weight and higher grain yield than higher levels of sulphur application in maize from his study. Yield attributes of maize such as length of cob, cob girth and individual cob weight, grain yield and stover yield increased with sulphur application at 20 kg ha^{-1} Srinivasarao *et al.*, (2010) [53]. Jeet *et al.,* (2012) [18] concluded increasing levels of sulphur application at 45 kg ha^{-1} increased the growth attributes like number of cobs plant^{-1}, length of cob, grain yield and stover yield in maize.

Choudhary *et al*., (2013) [8] obtained a significant increase in grain yield (4606 kg ha^{-1}) and stover yield (7115 kg ha^{-1}) with application of 40 kg sulphur ha^{-1} compared to control. Shivran *et al.*, (2013) [47] registered a significant increase in number of cobs plant^{-1} with application of sulphur at 60 kg ha^{-1} (1.48) over 30 kg ha^{-1} (1.46) and no application (1.33). Similar trend was also found with seed yield (42.83 q ha^{-1}) and stover yield (93.92 q ha^{-1}). Ali *et al.*, (2013) [53] found that application of sulphur at 25 and 35 kg ha^{-1} gave a significant increase in yield attributes such as no. of days to tasseling and silking, leaf area index at tasseling stage, length of cob, grain number row^{-1} and seed index than other treatments. Wang *et al*., (2014) [57] stated that sulphur application increases the grain yield of maize crop. Dibaba *et al.*, (2014) [12] divulged that application of sulphur at 40 kg ha^{-1} gave maximum grain and stover yield in maize which was statistically on par with 30 kg ha^{-1}. Jaliya *et al*., (2015) [17] documented that application of sulphur at 5-15 S kg ha^{-1} produced gave maximum grain yield in maize. Padma *et al*., (2018) [31] concluded that application of sulphur 60 kg ha^{-1} gave higher number of grain rows cob^{-1}, more number of cobs plant^{-1}, higher grain yield (5596 kg ha^{-1}) and stover yield (6995 kg ha^{-1}) compared to no application of sulphur in maize. Sanchez *et al.*, (2019) registered that application of sulphur at 50 kg ha^{-1} significantly increased the number of grains row^{-1}, thousand grain weight and 42% higher yield in maize compared to control.

Effect of sulphur application on nutrient uptake of maize

Ray and Mughogho (2000) [41] found a significant increase in sulphur uptake by grains with application of 10 to 30 kg ha^{-1}. Dwivedi *et al*., (2002) [13] registered that sulphur application significantly increased the sulphur uptake of grain, stover and total sulphur uptake in maize crop. Pandey *et al*., (2002) [1, 33] concluded that sulphur uptake was higher with sulphur application at 20 mg kg^{-1} of soil which is on par with application of 40 kg S ha^{-1}. Majumdar *et al.*, (2002) [22, 23] recorded a significant increase in sulphur uptake with increasing levels of sulphur to 60 kg ha^{-1} in the range from 2.58 to 9.44 kg ha^{-1} in than higher levels in maize. Patel *et al*., (2003) [34, 35] recorded a significant increase in sulphur uptake by maize with maize application. Mehta *et al.*, (2005) [26, 56] reported that application of sulphur at 60 kg ha^{-1} gave highest sulphur uptake by maize grains and stover from his study. Bharati and Poongothai (2008) [6] found that increasing levels of sulphur significantly increased the sulphur uptake of grain, stalk and also increased the nitrogen uptake from 208.9 to 244.2 kg ha^{-1} in maize. Higher nitrogen content was found in flag leaves of maize with application of 15 kg sulphur ha^{-1} than lower levels and control Jaliya *et al.*, (2012) [17]. Sarfaraz *et al*., (2014) [46] concluded that application of sulphur by foliar means at 20 kg ha^{-1} during knee high stage and silking stage gave significant increase of N, P, K uptake in maize crop from his study. Phosphorous and sulphur uptake in maize grains and dry matter were significantly higher with application of 50 kg sulphur ha^{-1} Imran *et al*., (2014) [15]. Irfan *et al.*, (2015) [16] documented higher values for sulphur concentration (0.44%) with 75 kg ha^{-1} than control (0.09%) in maize. Padma *et al.*, (2018) [31] concluded that nutrient uptake of plants and grain were higher with application of 60 and 80 kg ha^{-1} of sulphur in maize crop from his study.

Effect of sulphur application on quality of maize

Das *et al*., (1975) [9, 34] documented that application of sulphur at 30 kg ha^{-1} gave 8 % increase in methionine and 5% increase in cystiene and protein content with 1% in maize crop. Sakal *et al.*, (2000) [43, 52] reported that application of sulphur at 40 kg ha^{-1} increased the crude protein content from 9.2 to 10.7% in maize grains than other treatments. Dwiedi *et al.*, (2002) observed a significant increase in protein content (10.64%) over control with application of 30 kg S ha^{-1} in maize. Majumdar *et al.*, (2002) [22, 23] obtained a significant increase in crude protein content with increasing dose of sulphur application in maize. Rasheed *et al.*, (2004) [40] observed significant increase in protein content of maize grains with application of 20 kg sulphur ha^{-1} than control. Maurya *et al.*, (2005) [25] reported that the protein content increases with increasing level of sulphur up to 150 kg ha^{-1}. Singh *et al.*, (2008) [8, 13, 14, 18, 20, 25, 32, 39, 43, 48, 51, 53] concluded that sulphur application at 60 kg ha^{-1} gave significant increase in quality parameters such as protein yield, carbohydrate and starch in maize. Srinivasarao *et al.*, (2010) [53] obtained a significant increase in crude protein content of maize with application of 20 kg sulphur ha^{-1}. Jeet *et al.*, (2012) [18] reported that sulphur application at 45 kg ha^{-1} in quality protein maize gave significant increase in lysine content (3.96%) and tryptophan content (0.81%) than other levels. Choudhary *et al*., (2013) [8] concluded that sulphur application at 40 kg S ha^{-1} increased the grain protein content (10.5%) over control treatment in maize (9.8 %). Navita (2014) [28] concluded that sulphur application resulted in maximum protein content (10.1%) in quality protein maize compared to control. Sanchez *et al.*, (2019) found a significant increase in grain hardiness and crude protein content of maize with application of 50 kg sulphur ha^{-1}.

Effect of sulphur nutrition on economics of maize

Patel *et al.*, (2004) [34, 35] found a significant increase in net returns with application of sulphur in the range from 20 to 40 kg ha^{-1} in maize crop. Maurya *et al.*, (2005) [25] stated that sulphur application at increasing levels up to 45 kg ha^{-1} gave maximum net returns and benefit cost ratio in maize. Higher gross income, net returns and benefit cost ratio were significantly higher with increasing doses of sulphur application up to 60 kg ha^{-1} in maize Ram *et al.*, (2006) [38, 39, 51]. Srinivasarao *et al.*, (2010) [53] noted a significant increase in net returns and benefit cost ratio with sulphur application at 20 kg ha^{-1} from his study. Singh *et al.*, (2010) [8, 13, 14, 18, 20, 25, 32, 39, 43, 48, 51, 53] registered maximum net returns and benefit cost ratio with sulphur application in maize compared to control treatment. Jeet *et al.*, (2012) [18] documented that application of sulphur at increasing levels up to 45 kg ha^{-1} gave higher net return and benefit cost ratio in quality protein maize. Kumar *et al.*, (2015) [47, 52] registered maximum gross income, net returns, benefit cost ratio were higher with application of sulphur at 50 kg ha^{-1} and remained at par with 25 kg ha^{-1} in maize crop. Padma *et al.*, (2018) [31] registered a maximum gross returns and benefit cost ratio with application 60 kg ha^{-1} of sulphur than control in maize.

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