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Sulphur Nutrition in Maize - A Critical Review

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ABSTRACT

Sulphur is increasingly being recognized as the fourth major plant nutrient after nitrogen, phosphorus and potassium. It is a key element in importance in the formation of proteins and ranks along with nitrogen and phosphorus. It also plays a key role in chlorophyll formation and oil synthesis. Sulphur requirement for optimal growth varies between 0.1 and 0.5% on dry weight basis of plants and it increases in the order gramineae sp. < leguminoceae < cruciferae. The efficiency of applied NPK fertilizers and the economics of their use are seriously affected under sulphur deficient conditions. Hence, higher crop yields may not be sustained. Field experiments on maize in different agro-climatic zones of the country showed that application of sulphur up to 45 kg ha^{-1} recorded higher growth, yield and yield attributes and also protein content with respect to quality parameters. However, S nutrient uptake by plants increases with the application of sulphur up to 60 kg ha^{-1} depending on the initial sulphur status of the soil. A panoramic view of sulphur nutrition in maize has been reviewed in this chapter.

Key words: *Sulphur, Maize, Growth, Yield Attributes, Yield, Protein Content, Nutrient Uptake.*

INTRODUCTION

Maize (*Zea mays* L.) is one of the important food grains and extensively grown worldwide for food and also as source of raw materials for manufacturing of several products such as corn sugar, corn flakes, corn oil and corn protein[51]. It is a miracle crop. It has very high yield potential, there is no cereal crop on earth which has so immense potentiality and that is why it is called 'queen of cereals'.

Maize being an nutrient extensive crop nutrient has higher sulphur requirement and is sensitive to its deficiency[81]. The newly evolved high yielding varieties of maize are more fertilizer responsive. The fertilizer responsive varieties have accelerated the depletion of S reserves in the soil, even from lower soil depths[91]. It is being realized that apart from the major nutrients, the role of secondary nutrients in general and sulphur in particular in increasing cereal production is well established. In recent years, sulphur deficiency has become an increasing problem in agriculture, which limits the crop production. Saalbach[100], reported maize yield loss to an extent of 10 to 30% and Pal and Singh[80], up to 35% due to sulphur deficiency.

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In general, cereals have high yield potential and low sulphur requirement. The sulphur requirement to produce one ton of cereals is rather low but its uptake per unit area becomes almost equal to that of oilseeds mainly due to higher productivity of cereals. Sulphur is an essential nutrient for all organisms due to its function in a large variety of processes[55].

Sulphur is attaining importance in all regions of the world because of frequent sulphur deficiencies in time and space[51]. Several factors contributing to sulphur deficiencies were reported by many researchers includes, the increased use of sulphur free high analysis fertilizers[15,70], and less use of sulphur containing pesticides along with multiple and high intensive cropping[117,59,113], leaching and erosion[46], restricted use of organic manures[101], and removal of crop residues for feed and fuel. The scenario of sulphur deficiency is more pronounced in alfisols compared to vertisols due to the low organic matter content. In sulphur deficient condition, the use efficiency of applied NPK fertilizers, the economics of their use may be seriously affected, and high yields may not be sustained[51]. Complete yield potential of a crop cannot be obtained where soil is suffering with sulfur deficiency, even irrespective of all the other nutrients application and under excellent management practices. Sulfur application at level of 5 tons ha^{-1} results in higher maize yield[1].

WHY SULPHUR?

Sulphur is one of the essential plant nutrients and its role in plant nutrition is well documented[67]. Sulphur plays a vital role in the primary metabolism of higher plants and involved in synthesis of secondary metabolic products in certain groups of plants[61]. It ranks along with nitrogen and phosphorus in importance in the formation of proteins. It not only influences yield but also improves crop quality owing to its influence on protein metabolism and oil synthesis[56,89]. It is involved in the synthesis of the essential amino acids, like cysteine, cystine and methionine[35,52,110,58]. Besides it is a constituent of vitamins-thiamine and biotin, sulphur glycosides and co-enzyme A[121]. It improves crop management through its favorable effects on environmental stress, resistance against pest and diseases[63,20,98,57]. Apart from increasing the crude protein content of fodders, sulphur reduces the nitrate levels in forages and improves their quality. When S is deficient in soil, full yield potential of the crop cannot be realized regardless of other nutrients even under good crop husbandry practices[97].

About 2% of the organic sulphur in plant is present in the water soluble thiol (-SH) fraction, and under normal conditions tripeptide glutathione accounts more than 90% of this fraction[21]. Sulphur requirement for optimal growth varies between 0.1 and 0.5% on dry weight basis of the plants and it increases in the order of gramineae sp.< Leguminoceae < Criciferae sp. The increased use of sulphur free high analysis fertilizers like diammonium phosphate (DAP) in place of single super phosphate (SSP) and lack of addition of organic manures over the years resulted in emergence of S deficiency [120].

SOIL SULPHUR POOLS

Soil sulphur exists in organic and inorganic forms. From the view point of plant nutrition inorganic sulphate is the most important, since this is taken up by plant roots[121]. However, sulphate-S which is the stable form of inorganic sulphur in aerobic soils-constitutes only a small part of total S in soils. The fact that most of the sulphur in agricultural soils occurs in organic combination is well documented [115,76]. and organic S decreases with depth[71.] Generally, more than 95% of soil sulphur is organically bonded with several hundred kilograms of organic sulphur present in the upper horizons of most soils. The sulphur supplying capacity of the soil is closely related to organic S pool and its mineralization in soil is good indicator of S supplying capacity[37].

FORMS OF SULPHUR IN SOILS

1. Solution SO_4^{2-}

This form of sulphur is present in soil solution mostly as sulphates of Na, K, Ca and Mg. Sulphate is absorbed by plant roots by diffusion and mass flow[114]. Insufficient sulfate nutrition reduces plant growth, vigor and resistance to abiotic and biotic stresses[105,54,57]. In soils containing 5ppm or more SO_4^{2-} all of the requirement of most crops can be supplied by mass flow. A concentration of 3-5 ppm of sulphate in soil solution is adequate for the growth of many plant species.

Concentration of sulphate sulphur or SO_4-S in soils fluctuates through out the year because of changes in the balance between atmospheric inputs, decomposition of plants, fertilizer addition, leaching, plant uptake and microbial activity. Usually low levels of sulphate are observed over winter and spring due to leaching, plant uptake, and low mineralization rates associated with low temperatures[13,36,99].

Sulphate-S is readily leached from surface soil[29,53], and such losses are greatest when monovalent ions such as K^+ and Na^+ predominates. However, leaching losses are least in acidic soils with appreciable amounts of exchangeable Al^{3+} and this form of sulphur is readily available to crop plants.

2. Adsorbed SO_4-S

This is the important source of sulphur in highly weathered soils in regions of high rainfall containing large amounts of Al and Fe oxides (Sequioxides). The retention of absorbed sulphates in soils depends on the nature of colloidal system, the pH, the sulphate concentration and concentration of other ions in the solution[41]. The sulphate is adsorbed by hydrous oxides of Al and Fe and on clay particles[82]. Sequioxides acquire positive charges under acidic conditions[84]. SO_4^{-2}-S adsorption capacity is higher under such condition and decreases as pH increases. In surface soils absorbed SO_4^{-2} accounts for less than 10% of the total sulphur present and one third of the total sulphur in absorbed form is concentrated in sub soils[115], due to the eluviation or leaching. Although crops can utilize absorbed SO_4^{-2} in sub soils, they may experience sulphur deficiency in the early growth stages until root development is sufficient to reach the subsoil.

3. SO_4 co-precipitated with $CaCO_3$ and other precipitated forms

This form of sulphur is an important part of total sulphur in calcareous soils where calcium sulphate can co- precipitate with calcium carbonate and forms an insoluble complex. Such form of sulphur is available to plants only when it is brought into solution, which is difficult and very slow process. Availability of such sulphur increases with decreasing pH and particle size of the calcium carbonate and increasing soil moisture content[95].

There are reports that elemental sulfur (S) can be used as a nutrient and an acidifier[62]. Plant nutrients availability and their uptake in calcareous soils can be enhanced by acidification which has large cumulative effects on the overall N balance and on the amount of soil nitrogen reserves[12]. Maize is highly responsive to S; making maize an ideal crop for sulfur application in the forms of elemental S and ammonium sulfate or urea, especially in alkaline and calcareous soils[38,129].

Sulphur deficiency symptoms in plants

Sulphur is increasingly being recognized as the fourth major plant nutrient after nitrogen, phosphorus and potassium whose deficiency is wide spread in India[128,119,72]. Sulphur deficiency in crops started to appear in late 1980s, first in high sulphur requiring crops such as oil seed rape and then in cereal and since the mid 1990s, sulphur fertilization has been recommended for all crops[90]. Developing leaves are the first ones to show symptoms of S deficiency[9]. Sulphur deficiency symptoms resemble those of nitrogen deficiency, because both are related to protein and chlorophyll deficiencies. Sulphur is not as mobile in plants as N, P and K and therefore sulphur deficiency symptom appear on younger leaves and deficient plants are generally stunted with short slender stalks[92]. Because of less mobility there is not much translocation of S from older leaves to younger leaves. Sulphur deficiency in plants therefore shows up in young leaves in the form of pale green colouration. However, the pale green colour from nitrogen deficiency tends to be most apparent in older leaves. S depletion is also accompanied by changes in metabolite concentrations such as decreasing levels of glutathione which were shown to repress sulphate uptake and assimilation[42].

Sulphur deficiency symptoms in Corn

Sulphur deficiency in characterized by a yellowing of the younger or new leaves of the corn plant. The specific symptoms are interveinal chlorosis, followed by reddening of stems and leaves starting from leaf edges and gradually spreading to midrib and older leaves remains green[122].

S is deposited from the atmosphere to the soil due to reductions in power plant S emissions. In addition, increased yields over time result in greater crop S removal from the field. Corn grain contains about 0.5 pound of S for every 10 bushels of grain, so about 10 pounds of S per acre is removed by corn that yields 200 bushel per acre. Additionally, less incidental S applications in fertilizers and pesticides may contribute to more S deficiency. Increases in no till, early planting, and heavy residue from high yields have also been implicated in increasing the occurrence of S deficiency[79].

Extent of Sulfur deficiencies at Country level

Deficiency of sulphur in Indian soils has been reviewed by many research workers[5o,22,83,116]. Sulphur deficiencies are wide spread in soils of Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, Rajasthan, Bihar, West Bengal and many parts of the southern India. The light textured soils particularly alluvial (Entisols, Inceptisols), coastal (Alluvial), laterites (Oxisols), and red (Alfisols) and even black soils (Vertisols) have been reported to be deficient in S[73].

In the early 1990s, S deficiency in Indian soils were estimated to occur in about 130 districts but recent soil fertility surveys by ICAR system based on the analysis of 60,000 soil samples have shown widespread S deficiency problem in 240 districts. The scenario of S deficiency is more predominantly observed in the states practicing the cereal based cropping system[39].

Critical limits of available sulphur in soils

A critical limit of available soil sulphur has been established by using various extractants and methods of estimation for few selected soils and crops.

Critical level of sulphur in soil for maize and in different countries

Extractant / methodology	Critical level of S	Country	Reference in soil (ppm S)
Potassium phosphate (500 ppm P)	4	Nigeria	Kang and Osiname (1976)
Monocalcium phosphate (500 ppm P)	8	U.S.A	Fox et al. (1965)
	4	Nigeria	Kang and Osiname (1976)
Sodium acetate and acetic acid	6	Nigeria	Enwezor (1976)
Ammonium acetate	4	Nigeria	Kang and Osiname (1976)

Critical limits of sulphur deficiency in maize plants tissue

The sulphate content in plants tissue is used as a sensitive indicator of S status in plants. Various extractants are used for this purpose which include water, acetic acid (2%), trichloro acetic acid, hydrochloric acid, formic acid and hypophosphorus acid, sodium hydroxide, acetone and ethanol. A detailed review of all these is given by Beaton *et al.*[5].

Total S concentration of the leaves also used as an index of sufficiency or insufficiency of S in the plant tissue. Kamprath and Jones (In Press) have presented considerable data from the United States and reported that maize responds well S fertilization particularly when tissue S content is less than 0.15%, significant response to fertilization with S occurred. Kang and Osaname considered 0.14% S as critical level of S in the ear leaf of maize in Nigeria. Diagger and Fox[25]. observed 0.24% S as critical level of S in the ear leaf of maize. By geographical method of Cate and Nelson (1965) critical concentration of S in the 60 days old maize plant tissue was found to be 1120 mg kg^{-1} (0.112%) on dry weight basis. Sakal *et al.*[102] reported a critical limit of 650 mg kg^{-1} for maize variety Ganga Safed-2. This variation in critical limits depends on type of extractants, soil types and cultivars used *etc*.

Effect of S fertilization on maize growth

Adequate sulphur is required for carbohydrate formation, thus it has role in photosynthesis by influencing the formation of chlorophyll. Bhagya Laxmi *et al.[6]*, reported that application of 60 kg S ha^{-1} recorded highest plant height. Sulphur is involved in the metabolic and enzymic process of all living organisms. Shrinivasrao *et al.[107]*, obtained favourable effects of sulphur fertilization @ 20 kg S ha^{-1} on plant height under Indian conditions. Gahlout *et al.[34]*, revealed that application of 45 kg S ha^{-1} recorded significantly higher plant height. However, Bharati and Poongothai[7], did not get significant increase in plant height and leaf length due to varying levels of sulphur from 0 to 45 kg S ha^{-1}. Maurya *et al* .[68], found that plant height, number of green leaves and leaf area index increase with increasing levels of sulphur from 0 to 150 kg S ha^{-1}. Ram *et al.* [96],found that sulphur application significantly increased plant height up to 60 kg ha^{-1}. Baktash[4], revealed that best results were obtained with 60 kg S ha^{-1} for plant height. Dhananjaya[24], reported an increase in the plant height of maize with increasing levels of sulphur application up to 45 kg S ha^{-1}. A two years field experiment was conducted by Choudhary *et al.*[17], results revealed that maximum plant height (291cm) at harvest was attained with application of 40 kg S ha^{-1} over control. Bhagyalakshmi *et al.[6]*, at Bangalore reported that among the sulphur levels, application of 60 kg S ha^{-1} recorded the highest plant height (267 cm) on sandy clay loam soil having slightly alkaline in reaction. Sulphur application promotes the production of plant growth hormones for improving better growth of plants. Gahlout *et al.[34]*, reported that the highest plant height (171.33 cm) of maize was obtained with application of 45 kg S ha^{-1} at Allahabad (Uttar Pradesh).

Total dry matter production of a plant often indicates its yield potential. It may vary through effect of weather change on photosynthetic system or length of growing season during which photosynthesis continues[127]. Rahman *et al.[93]*, recorded higher total dry matter accumulation with application of elemental sulphur at 5 t ha^{-1}. Khan *et al*.[51], concluded that application of sulphur through gypsum @ 60 kg S ha^{-1} produced highest yield of fresh matter and dry matter resulting in increase of 41 and 55%, respectively. Maurya *et al.[68]*, reported increase in dry weight with increase in sulphur application up to 150 kg S ha^{-1}. Pandey *et al.[81]*, noted that application of sulphur at 20 mg/kg soil significantly increased dry matter yield. Fontanetto *et al.[31]*, stated that application of sulphur at 24 kg S ha^{-1} recorded highest dry matter yield than preceding levels. Ahmed *et al.*[1], reported that increase in S levels, plant height was increased from 186 cm in the control to 209 cm @ 30 kg S ha^{-1}. This showed that plant height increased by 12.36% over no sulfur application. However, further increased beyond @ 30 kg S

ha^{-1} did not show any increases in plant height suggesting it as optimum dose in the prevailing soil and plant conditions. Tirupathi *et al.*[120], found that growth parameters like plant height (180 cm), leaf area index (3.0) and drymatter (234.7 g plant^{-1}) were increased significantly with increasing levels of sulphur up to S3 (60 kg ha^{-1}) thereafter though the sulphur level increases up to S4 (80 kg ha^{-1}) the growth parameters were decreased slightly but it was comparable with S3 (60 kg ha^{-1}). Nanthakumar *et al*.[74], conducted an experiment during *rabi* season in farmers field in sivagangai district, Tamilnadu, results revealed that maximum plant height (170.7 cm) at 90 DAS was recorded with application of 80 kg S ha^{-1} compared to 60, 40, 20 kg S ha^{-1} and control

Effect of S fertilization on yield attributes of maize

The plant requirement for sulphur is mainly responsible for nitrogen availability hence with the increasing rate of sulphur, the availability of nitrogen and it uptake increases. Bhagya Laxmi *et al.*[6], noted that application of 60 kg S ha^{-1} recorded highest cob length and 100 grain weight of maize. Application of 20 kg S ha^{-1} recorded highest cob length, cob weight and 100 grain weight[107]. Gahlout *et al.*[34], revealed that application of 45 kg S ha^{-1} recorded significantly higher number of grains per cob and 100 grain weight than preceding levels. Bharati and Poongothai[7], concluded that the application of 45kg S ha^{-1} recorded better 100 grain weight. Khan *et al*.[51], concluded that application of 60 kg S ha^{-1} recorded higher weight of 100 grains which was on par with 40 kg S ha^{-1}. The application of 60 kg S ha^{-1} recorded the higher yield attributes like cobs per plant, rows per cob, cob weight and grain weight per cob over the preceding levels[69,110,113]. Application of 45 kg S ha^{-1} increases yield attributes over its lower levels[68]. Baktash[4], noted that best results were obtained with 60 kg S ha^{-1} for cob length, number of rows per cob and number of grains per cob. Mandal and sikder[65], reported an increase in dry matter yield with 30 kg S ha^{-1}.Dhananjaya[24], revealed that number of cobs per plant increases with increasing levels of sulphur up to 45 kg S ha^{-1}.Ojeniyi and Kayode[78], reported that the application of 80 kg S ha^{-1} recorded the higher cob weight compared to the other treatments. Shivran *et al.*[106], reported that maximum number of cobs plant^{-1} was obtained with application of 60 kg S ha^{-1} (1.48) than 30 kg S ha^{-1} (1.46) and control (1.33). A two years field experiment was conducted by Choudhary *et al* .[17], at Udaipur region of Rajasthan and reported that application of 40 kg S ha^{-1} recorded the highest grain yield (4606 kg ha^{-1}) and stover yield (7115 kg ha^{-1}) than control. Sulphur application facilitates more number of bigger size cobs that might have accommodated number of grains providing sufficient space for development of individual grain, leading to higher test weight with sulphur application resulting in higher grain weight cob^{-1} (Ahmed *et al.*[1].

Effect of S fertilization on Maize Yield

Sulphur deficiency and yield response to its application have been reported both from irrigated and rainfed farming systems[3,16,18,2].The magnitude of yield depends on degree of sulphur deficiency, yield potential of crop, nutrient interaction and rate of application. Sulphur encourages photosynthetic activity by increasing chlorophyll pigments, synthesis of essential amino acids and proteins, translocation and utilization of starch and nitrogen and all these functions finally converge to increase maize yield .Application of sulphur improves yield of crop[88,116]. Bhagya Laxmi *et al.*[6], stated that application of sulphur through bentonite at 60 kg ha^{-1} recorded higher grain and stover yield. Gahlout *et al.*[34], obtained highest grain yield with the application of 45 kg S ha^{-1}. Shrinivasrao *et al.*[107], revealed that application of 20 kg S ha^{-1} increases grain yield by 0.59 t ha^{-1} over control. Application of 60 kg Sha^{-1} significantly increased the grain and stover yield[111]. Addition of 30 kg S ha^{-1} increased the grain yield of maize significantly[66]. Bharathi and Poongothai[7], recorded 16.85% increase in yield with application of sulphur at 30 kg ha^{-1} compared to control. Khan *et al.*[51], obtained highest stover yield with application of 60 kg S ha^{-1}. Application of 60 kg sulphur through gypsum @ 60 kg ha^{-1} recorded highest grain and stover yield over lower levels in Rajasthan conditions[69]. Biswas *et al.* [8],found that optimum S rate varied between 30 and 45 kg ha^{-1} in most of the agroclimatic zones of the India and maize yields increase from 11 to 93% due to application of sulphur. Maurya *et al.*[68], reported increase in grain and stover yield with increase in sulphur application up to 150 kg S ha^{-1}. Ram *et al.*[96], recorded significantly higher yield by application of 20 kg S ha^{-1}. Majumdar *et al.*[64], recorded significantly higher yield by application of 20 kg S ha^{-1}. Patel *et al.*[86], reported an higher yield with application of S level of 40 kg ha^{-1}. Application of 40 kg S ha^{-1} enhanced the average grain yield of maize by 0.99 t ha^{-1} [103].Toatia *et al.*[123], reported highest stover yield in treatments receiving 80 kg S ha^{-1}. Fontanetto *et al.*[31], noted significant increase in stover yield with application of 24 kg S ha^{-1}. Application of 45 kg S ha^{-1} recorded higher grain and stover yield[24]. Haq *et al*.[40], found a 20.5% increase in the grain yield with 72 kg S ha^{-1}. Addition of 22.4 kg S ha^{-1} in the form of ammonium sulphate increased the yield of maize up to 43.4% compared with the control[109]. Das *et al*.[19], reported that on an alluvial soil with 10 ppm available sulphur, the application of 30 kg S ha^{-1} increased maize grain yield by 4.7 q ha^{-1}, this increase being 9%. Pasricha *et al*.[88], and Dev *et al.*[23], found that S application up to 25 ppm was useful to produce optimum yields of maize in an alluvial soil. Rahul[94], found that application of 90 kg S ha^{-1} significantly raised the yield of maize in S deficient soils of Rajasthan. Grain yields were increased with addition of 11 kg S ha^{-1} compared to the check treatment[11]. In one of the study Shivran *et al*.[106], reported that maximum seed yield (42.83 q ha^{-1}) and stover yield (93.92 q ha^{-1}) was obtained with 60 kg S ha^{-1} over control and 30 kg S ha^{-1}. Similarly, Choudhary *et al.*[17], reported that application of 40 kg S ha^{-1} recorded the highest grain yield (4606 kg ha^{-1}) and stover yield (7115 kg ha^{-1}) than control. Sharma *et al.* found that application of 100% NPK along with 40 kg S and 6 kg Zn ha^{-1} recorded significantly higher mean grain yield by 9.9 and 22.5% and stover yield by 7.8 and 19% over 100% NPK and S and 100% NPK respectively. Wang *et al*.[126], revealed that maximum grain yield was found in split application of sulphur (11853 kg ha^{-1}) and the minimum grain yield obtained with conventional application of sulphur (9988 kg ha^{-1}), in an trial on sulphur application times on the sulphur accumulation and distribution in maize.

Effect of sulphur fertilization on quality of maize

Sulphur is considered as quality element[124]. In maize the important quality parameters like carbohydrates, starch and protein yields are affected by sulphur. Sulphur improves the quality of crop as it has direct impact on the various biochemical reactions in the plant and takes part in the chlorophyll formation. Several research reports state that lack of S-containing amino acids is the main factor limiting the biological value of proteins[111].

Sulphur being a constituent of essential amino acids *viz*., cystein and methionine, application of sulphur increases the amount of these amino acids in plant system. Deficiency of either nitrogen or sulphur limits protein production of plant[125]. Sulfur fertilization is most critical for oil, protein synthesis and for improvement of quality of produce by their enzymatic and metabolic efforts[60]. Singh *et al.* noted that application of sulphur at 60 kg ha^{-1} recorded highest quality parameters, such as carbohydrate, starch and protein yields. Maurya *et al.*[68], reported that the protein content increases with increasing level of sulphur up to 150 kg ha^{-1}. The application of 30 kg S ha^{-1} recorded the better average protein content (10.64%) compared to other treatments[27]. Majumdar *et al.*[64], found that crude protein level increases with increasing level of sulphur. Crude protein content increased from 9.2 to 10.7% in grains with the application of 40 kg S ha^{-1} level[103]. Das *et al*.[19], showed that sulphur application 30 kg S ha^{-1} resulted in 5 % increase in cystine and 8%

increase in methionine and 1% increase in protein content. A two years field experiment by Choudhary *et al*.[17], at Udaipur region of Rajasthan, results reported that application of 40 kg S ha^{-1} recorded the highest crude protein content in grain (10.5%) than control (9.8 %). In one of the study highest lysine (3.96%) and tryptophan (0.81%) content were recorded in quality protein maize hybrids with application of 150 kg N and 45 kg S ha^{-1} but it was on par with 100 kg N and 45 kg S ha^{-1} (3.87 %) and (0.77 %) compared to other levels at eastern UP[47]. Grain protein content of quality protein maize as influenced by (M2) i.e. split application of sulphur as basal and at knee high stage of sulphur resulted in higher protein content of 10.1% compared to basal application of sulphur 9.69% (M1), respectively[75].

Effect on N uptake by Maize

For the synthesis of sulphur containing amino acids, assimilatory reduction reaction of both sulphate and nitrate are necessary and therefore nitrogen and sulphur uptake and assimilation are closely liked[10]. N metabolism is strongly affected by the S status of the plant[45,26]. Fismes *et al.* [30], have shown S deficiency can reduce nitrogen use efficiency. Increasing levels of sulphur progressively enhanced the N uptake of maize from 208.9 to 244.2 kg ha^{-1} [7]. Mehta *et al*[69], concluded that highest N uptake by grain and stover recorded with 60 kg S ha^{-1}. Increasing levels of sulphur progressively enhanced the total N uptake by maize from 64.72 to 88.69 kg ha^{-1} [27].Sakal *et al.*[103], reported higher N uptake by grain and stover in treatment receiving 60 kg S ha^{-1} than preceding levels. Niaz *et al*.[77], observed that application of nitrogen @ 200 kg N ha^{-1} recorded the highest N uptake by plant (173.86 kg ha^{-1}) than 125,150 and 175 kg N ha^{-1}.

Effect on S uptake by Maize

The depth of the radical and seminal roots, amount of residue cover and the drainage of water through the soil profile are the key factors influencing S uptake in maize. It is reported that the uptake of sulphur is about 3 to 4 kg by cereals[118].

Srinivasarao *et al.*[107], recorded higher uptake of S with application of 20 kg S ha^{-1}. Bharati and Poongothai[7], noted that uptake of sulphur by grain and stalk increased significantly with increasing levels of sulphur. Mehta *et al.*[69], concluded that highest sulphur uptake by grain and stover recorded with application of 60 kg S ha^{-1}. Patel *et al*.[87], recorded 8 kg S ha^{-1} uptake by maize. Dwivedi *et al*.[27], reported that application of sulphur significantly increased the sulphur uptake by grain, stover and total sulphur uptake from 4.11 to 5.85, 1.85 to 3.53 and 6.91 to 9.34 kg ha^{-1}, respectively. Pandey *et al.*[81], reported a higher uptake of S with application of 20 mg/kg of soil which is equivalent to application of 40 kg S ha^{-1}. Majumdar *et al.*[64], reported an increase in S uptake with increasing levels of sulphur. Total S uptake progressively increased from 2.58 to 9.44 kg ha^{-1} in treatment receiving 60 kg S ha^{-1} than preceding levels[103], The highest value of S concentration (0.44%) was recorded in where P and S were applied at the rate of 90 kg ha^{-1} P + 75 kg ha^{-1} S and lowest S (0.09%) concentration was recorded in control plot, in a study by Irfan *et al.*[44]. Comparative effect of soil and foliar application study on sulphur on maize by Sarfaraz *et al*.[104], revealed that foliar application of sulphur at 20 kg ha^{-1} at knee heigh stage and silking stage gave maximum N, P, K uptake (44.7 kg ha^{-1}, 20.3 kg ha^{-1}, 99.5 kg ha^{-1}) than soil application. Imran *et al*.[43], during spring season maize revealed that Phosphorus and sulphur uptake by dry matter and grain significantly increased by the addition of S @ 50 kg ha^{-1} along with NPK fertilizer.

CONCLUSIONS

- Use of high analysis fertilizers containing little or no sulphur coupled with intensive cropping system has caused wide spread sulphur deficiencies in plants. Efficiency of applied N, P_2O_5 and K_2O and the economics of their use is seriously affected under sulphur deficient conditions.

- Sulfur cannot be neglected any more in the interest of sustaining ever increasing targets of agricultural production through balanced and efficient crop nutrition
- Optimizing the plant availability of sulphur in appropriate quantities and in synchrony with plant demand is necessary in achieving high yield levels.
- On S-deficient soils, potential yields, quality and profits are possible only if deliberate S application is made a part of fertilizer application plan.
- Field experiments on maize in different agro-climatic zones of the country showed that maize responds well to the application of sulphur up to 45 kg ha^{-1} resulting in higher growth, yield and yield attributes and also protein content.

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