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Sulphur and its significance in higher pulse production

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ABSTRACT

Sulphur is one of the emerging plant nutrients, required for pulse crops. After nitrogen, phosphorous and potassium, it is forth key nutrient for plant nutrition. It is taken up by the plants in the form of sulphates form from the soil. The factors that are responsible for the wide spread deficiency of sulphur are excess use of high analysis fertilizers, inadequate use of crop residue, high yielding varieties of crops and its removal of sulphur by the crops. Sulphur plays a pivotal role in overall pulse production, by synthesis of sulphur containing amino acids, enhancing protein content, nodule formation and plant biomass. However, the requirement of sulphur for effective crop production is not showing promising trend. Comparing the sources of sulphur fertilizers, gypsum showed its superiority by producing high grain and straw yield in pulses. In some of the field experiments on pulses, addition of sulphur @30kg and 40kgof S/ha along with the recommended dose, increased the growth (plant height and number of branches) and yield and quality parameters (grain yield and protein content). This review highlights the different response of crops to Sulphur application, sources, uptake and its interactions with other nutrients for profitable crop production. Moreover, it provides new insights to revisit the significance of sulphur in higher pulse production.

Introduction

Pulses are the leguminous crops, which are harvested mainly for dry seed purpose. The most commonly consumed pulses are green gram, chick pea, lentil, dried beans, peas and grams etc. These are the distinguished plants having high protein contents with the excellent dietary fiber content and other complex carbohydrates. Pulses are regarded as a curator in maintaining soil fertility, by virtue of which it fixes the atmospheric nitrogen through root nodules in soils. Although, India is the largest producer (25%) as well consumer (27%) of pulses yet it has to import 14% of pulses from abroad for sustenance of her burgeoning population. Pulses accounts for about 20% area under food grain (Mohanty, S and Satyasai, 2015). It is worth noting that the production of pulses per area is not satisfactory. The current demand for pulses is about 20 to 25 million tons and will be rising eventually in further upcoming days. There is need to bring more area under pulse production and augment the production. India is in foremost position is chickpea (*Cicer arietinum*), pigeon pea (*Cajanus cajan*), urd bean (*Vigna mungo*) and green gram (*Vigna radiata*) production. In our country, gram is the most prevalent pulse crop, which is contributing around 40% of its total production followed by pigeon pea and urdbean. The top most pulse growing states includes Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh and Karnataka (Mohanty and Satyasai, 2015). Pulses can be grown either as a kharif or rabi crop and can act both as a fodder for livestock and green manure for the next crop in sequence by enriching the soil. Factors responsible for sulphur deficiency include excess use of high analysis fertilizers that are free from sulphur, multiple and intensive cropping systems, reducing use of the organic manures (Khurana *et al.* 2003, Shivay *et al*. 2014) leaching

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losses in coarse textured soils (McNeill *et al.,* 2005). The deficiency of sulphur is not only prevalent in India but it is global (Tripati *et al*., 2003).

Sulphur as a nutrient

Among the major nutrients, sulphur is said to be the fourth important nutrient, which is mostly required for leguminous and cruciferous crops. Sulphur is treated as a mandatory nutrient, for its role in development and metabolism of the crop plants (Vidyalakshmi *et al*., 2009). Sulphur plays a crucial role in forming sulphur containing amino acids viz., methionine, cystine and cysteine, protein synthesis and root nodule formation. It is present in top most layers of the soil and shows decreasing trend with increase in depth. Sulphur has an important place in growth, production, development and yield attributes in legumes and oilseeds. There exit a greater variation in distribution of total sulphur present in the soil, due to the difference in soil characteristics. It is now recognized that sulphur, being a limiting factor, affecting production of crops in semi-arid tropical regions, covering around 73 million hectares of vertisols and other associated soils in India (Rao and Ganeshamurthy, 1994). Pulse production can be drastically increased to a greater extent, by the application of this nutrient. Though sulphur is not an integral part of chlorophyll yet its deficiency leads to chlorosis. Higher sulphur fertilizer requirement is seen in different regions of Asia. In soils, sulphur is obtained from sulphur containing minerals and from plant and animal residues.

Total /available sulphur in soil

The most common sources of sulphur are elemental sulphur, sulphide and sulphate minerals. In soils, the total sulphur content is ranging from 30 to 400mg kg^{-1}. Out of this, only a minute proportion is made available to the growing plants. The critical deficiency value of available sulphur is taken as 10 mg S kg^{-1}. The sulphur is absorbed by the plant roots, from the soil, in sulphate form (SO_4^{2-}) (Schoenau and Mahli, 2008). In general, the available sulphur varies with respect to different soil types and its results are compiled by Hedge *et al.* (1980) stating that more than 10% of total sulphur is taken as an available sulphur in hilly red and alluvial soils, where paddy is main crop. Mahto *et al.* (1992) confirmed that the alkaline soils of Chota Nagpur region of Bihar contained higher amounts of available sulphur whereas acidic soils contained highest amount of total sulphur. Singh *et al*. (1993) recorded that the soluble sulphur is present in small proportions compared to total sulphur that resulted in 60% deficiency in soils of Chota Nagpur region particular in coarse textured soils where leaching loss of SO_4^{-2} - S is prominent.

Sulphur exists both in both organic and inorganic forms in soil, depending on different factors such as soil texture, organic matter, pH, calcium carbonate and other soil properties (Dhamak *et al.,*2014). Organic form of sulphur is >90%, which is present in humus and other crop residues (Freney,1986). The inorganic sulphur includes pyrites (FeS_2), Gypsum ($CaSO_4.2H_2O$), elemental sulphur and SO_4^{2-}. In Alluvial soils, the total sulphur contributes about 30% in organic forms as against 70% in Mollisols of Tarai region in India (Singh *et al.,* 2015). In general, the sulphur content is low in tropical soils owing to a lesser amount of organic matter, parent material and leaching losses (Olson and Engelstad 1972; Rego *et al.,* 2007). It is estimated that 8kg of sulphur is needed to produce one ton seed of pulses (Jamal *et al.,* 2010).

Sulphur content in plants

Plants take sulphur in SO_4^{2-} forms, which is stored in xylem tissues and vacuoles of the plant cells, in an aqueous solution. But it is present in the plant tissues as S^{2-} (sulphide) or SH^- (thiol or sulfhydryl group) in different organic molecules along with the proteins. Comparing S concentration in grain and straw, Aulakh *et al*. (1985) found that, the grains contain more S content and cruciferous showed wider variation than pulses. Reddy *et al*. (1988) stated that, in cereals 0.16% - 0.25% is the optimal range of S and below 0.20% is referred as a sub optimal range. Khurana and Bansal (2007) established the critical limit of Sulphur in whole shoot in moong to be 0.23%.

Response of pulses to sulphur application

Results of several experiments showed that the yield response of sulphur application differed in magnitude in different pulse crops. A field experiment, conducted on loamy typic soils of Uttar Pradesh by Tripathi *et al.* (1997) in chickpea crop, showed a significant response to 40 kg S ha^{-1}. Ram and Dwivedi (1992) stated that sulphur application increased the yield of chickpea to tune of 2.13 tons ha^{-1} over control in first and second year when sown in sulphur deficient soil. In black gram, the grain and straw yield increased up to 20% over control, due to sulphur application in 1992 and 1993 respectively (Dwivedi *et al.,* 1996).

Singh *et al*. (1997) noticed that the application of sulphur not only improved grain and straw yield but also the nodule formation and plant biomass. Application of sulphur up to15 kg ha^{-1} increased the bacterial population but beyond that it decreases both the fungal and actinomycetes population. On the basis of availability coefficient ratio (ACR), among all the sulphur carriers, the response of gypsum was found to be highest whereas the elemental sulphur was least, with respect to grain and straw yield. There has been a drastic increase in the total number of nodules and active nodules by the application of sulphur up to 20 kg ha-1 (Ganeshamurthy and Reddy, 2000). The importance of sulphur showed a remarkable increase in pod length, number of pods per plant and grains count, when applied at the rate of 60 kg/ha to black gram (Patel *et al.,* 2018). Sulphur application not only increased the nodule formation in black gram (Khandkar *et al.,* 1985) but also involved in forming a nitrogenase enzyme, that fixes nitrogen in legumes (Saraf, 1988; Scherer *et al.,* 2006). Khurana *et al*. (2004) concluded that significant increase in grain yield of moong was obtained at and above application of 20 kg S ha-1, when grown in coarse textured alluvial soil.

In green gram and pea, sulphur application showed a significant response to total chlorophyll content (Poorani, 1992; Spencer *et al.,* 1990). Addition of sulphur at the rate of 40 kg ha^{-1} improved the plant height, number of branches, pods per plant and 1000 gram weight in green gram crop. Sulphur is well known for its role in enhancing the quality of pulses. In summer green gram, when S applied at the rate of 30 kg ha^{-1} showed a maximum plant height, leaf area index, increase in the number of branches and dry matter content, when compared to other levels (Sitaram, 2010). An experiment was conducted by Patel *et al.* (2013) by employing three different levels of sulphur through gypsum (0, 20, 40 kg ha^{-1}) in the presence and absence of phosphorus and bio-fertilizers, only 40 kg S ha^{-1} was required to be applied to chick pea crop for getting maximum branches per plant, number of nodules, plant spread, dry matter, protein content, seed yield along with the highest net realization. Further application of 40 kg S along with the P_2O_5 ha gave a maximum grain yield than sulphur alone. Hence it is proved that phosphorus and sulphur have a combining effect on the productivity of pulses.

In a cropping sequence involving mung-bean--raya (*Brassica juncea*), Khurana and Bansal (2007) observed that sulphur applied @ 20 kg ha^{-1} to each crop or 40 kg ha^{-1} to the first crop (mung bean) was sufficient to obtain optimum yields of both the crops. Khurana *et al.* (2008) while describing sulphur nutrition of various crops in Indo Gangaetic Plains of South Asia observed that for normal yields, the crops with high sulfur requirements (like oilseed, pulses, groundnut, alfalfa , garlic and onion) need 20 to 45 kg sulfur ha^{-1}. Crops with medium sulfur requirements need 15 to 35 kg sulfur ha^{-1}. Results of several experiments pertaining to responses of pulse crops summarized by Tandan and Messick (2007) under field condition is given in table 1.

Table 1: Average responses of crops to S application under field conditions (Tandon and Messick, 2007).

Pulse Crop	No of field experiments	Average rate of S application kg S ha^{-1}	Response to S kg grain kg S^{-1}
Chickpea	6	85	5.3
Pigeonpea	8	36	8.9
Black gram	9	30	5.4
Green gram	6	40	3.3

Effects of different sources of sulphur in Pulses

Sulphur is made available to the crop, through various sources such as gypsum, pyrite, elemental sulphur, single super phosphate, ammonium sulphate and, potassium sulphate. As the plants take sulphur in sulphate form, only the sulphate- S containing materials are said to be suitable for neutral to slightly alkaline soils. In coarse textured soils, the deficiency of sulphur occurs more often (Aulakh, 2003). Hence the sulphate -S becomes more susceptible to leaching losses in such soils. Under such conditions, the response of gypsum is higher compared to any other source. Gypsum, being sparingly soluble, it can supply sulphur to the crops for longer duration. It has been reported that gypsum application gave an excellent results regarding various growth factors (plant height, leaf area index, production of dry matter and number of branches/plant and yield (number of pods per plant, number of seeds per pod, grain and hulm) parameters in black gram (Patel *et al.*, 2018).

Banik and Sen Gupta (2012) reported that, when 30 kg SSP is applied along with the recommended dose of N,P and K. They obtained a maximum seed yield compared to other sources in green gram. The available SO_4^{2-} - S, present in gypsum is the main reason behind increasing the grain and straw yield when compared to pyrite and elemental sulphur. In summer moong (*Vigna radiata L.),* Singh and Chibba (1991) found while comparing different S sources viz ammonium sulphate, super phosphate, gypsum , elemental suphur and pyrite respectively that there was significant response to sulphur application for maize and wheat crops grown on S deficient soil irrespective of the sources. For maize ammonium sulphate, super phosphate, gypsum and elemental suphur were at par in their performance. But in case of wheat ammonium sulphate was most efficient followed respectively by super phosphate, elemental suphur and pyrite/ gypsum.

Dhillon *et al.* (1978) studied the effect of three carriers of sulphur namely gypsum, elemental sulphur and ammonium sulphate with three levels of sulphur (0,5 and 10 ppm) on soybean in a pot experiment. Results showed that efficacies of ammonium sulphate, gypsum and elemental S were in order of highest, intermediate and least respectively. Large quantities of indigenous S sources such as mined gypsum, pyrite and by-product phospho- gypsum are available in the country. Research efforts have been directed to evaluate suitability of these indigenous S sources as sulphur fertilizer in soils and crops of eastern India. Basal soil application of gypsum and phosphor-gypsum were found to be superior than that of pyrites. However, pyrites resulted in higher crop response on residual sulphur in various cropping systems (Singh and Singh, 2016).

From the compilation of results of various experiments, it is inferred that in calcareous soils, non calcareous soils and acid soils, elemental S was about twice, 80% and 50% as effective as gypsum respectively.

Uptake of sulphur in Pulses

Although the sulphur uptake ranges from 5 to 30%, but in general it varies from 9 to 15% as that of nitrogen. In crops like mustard, the uptake of sulphur is very high and almost equal to one third of nitrogen. More often it is seen that crop absorbs sulphur similar to that of phosphate. To produce 1 kg of grain, the uptake of sulphur for pulses is 8 kgs (range 5-13), is 12 kgs(range 5-20) and for cereals it is 3 to 4 kgs(range 1-6) (Tandon and Messick, 2002). Higher the requirement of sulphur, higher will be the crop yield. Results of several experiments pertaining to S uptake of pulse crops summarized by Tandon and Messick (2007) under field condition is given in table 2.

Table 2: Average Sulphur uptake by pulse crops.

Pulse Crop	Yield (kg/ha)*	Sulphur uptake, kg/ha
Chickpea	1500	6
Pigeonpea	1200	9
Black gram	600	5
Green gram	870	7
Lentil	2000	9

***Several Indian publications Tandon and Messick (2007)**

Among the different sources of sulphur, the uptake of sulphur was found to be high where gypsum was used followed by super phosphate, pyrites and press mud. Ram and Dwivedi (1992) recorded that, by applying sulphur to chickpea, the uptake of N,P,K and S was higher than the control In black gram and lentil crop, the S content and uptake increases with the increase in the pyrite levels as reported by Singh *et al.* (1992).

Quality and nutritional aspects of Sulphur in Pulses

Review of many authors indicated that the sulphur has gained a greater importance in pulse production by increasing the seed yield and protein content. Pulses contains on an average 20-25% proteins It is seen sulphur not only enhanced yield but also protein content along with the sulphur containing amino acids, in the crops like chick pea and green gram etc. Tiwari (1995), while working on the rain fed soils of Eastern UP reported that application of 40 kg elemental S ha^{-1} increased seed yield and protein content of lentil by 6.5%. But 80 kg ha^{-1} elemental S is required to increase protein content in green gram and chick pea to the tune of 3.5 and

2.7 % respectively. In West Bengal, 45 kg S ha^{-1} enhanced protein content by 12% in black gram (Sen, 2006). In Jharkhand, residual effect emanating from the earlier application of $80kgSha^{-1}$ recorded 13% increase in protein of black gram (Singh *et al.*, 1998).

Dhillon and Dev (1980) stated that, sulphur application in soyabean improved significantly the proportion of sulphate-S and protein-S. But sulphur as a whole is not utilized by the plants for protein content. Only the requisite amount of S is required for good quality grain. So there is no need of excess S application so as to prevent the accumulation of SO_4^{2-} -S in plants. In groundnut and mustard, S application caused exceptional increase in protein, oil and methionine content (Singh *et al.*,1970). Aulakh and Sharma (2005) reported that the application of sulphur showed significant beneficial effects on yield as well as protein in some pulse crops. When 60 kg of sulphur per hectare is applied to sesame crop, 11% increase is observed in protein and oil content. It also resulted in increase in 11% in oil and 5% in protein content in the succeeding mustard crop (Singh and Tiwari, 1985). For adequacy of sulphur, nitrogen to sulphur ratio is considered as a good indicator in plants. The ratio of N:S ranges from 13 to 17 in green gram.

Sulphur interaction with the other nutrients

Sulphur when applied with the other nutrients, its effects can be amplified or diminished. However, it is fascinating to know that the nature of two nutrients in green house differ from the field conditions. For example, under greenhouse conditions, antagonistic effect was recorded by the combined application of S and P on yield, uptake and protein content in green gram, whereas the deleterious effects were recorded only at a maximum rate under field conditions. It was found that, the combined application of P and S enhanced the nodulation activity. Sulphur's effects might be enhanced or decreased when coupled with other nutrients. For diverse legume crops, it exhibited a synergistic impact for N, K, Ca, and Mg and an antagonistic effect for P, Mg, and Mo (Abdin *et al.*, 2003). In genotypes of chickpea - modulating and non-modulating, the sulphur deficiency resulted in decrease in accumulating N^{15} in the root and shoot portion in both genotypes, thereby decreasing the accumulation of K^{+}, Fe^{2+} and Zn^{2+} while increasing Mg^{2+} and NO_3^{2-}(Badruddin and Karmokee, 2001). The key elements N-S interactions are regulated by NO_3^{2-} and SO_4^{2-} uptake, coupled with regulation of nitrate reductase and variations in the level of O-acetyl-ser.

Conclusion

Sulphur is the essential plant nutrient for synthesis S containing amino acids like cysteine and methionine. Different researches revealed that, sulphur fertilization to pulse crops showed higher increase in crop yield and protein content. There are different sulphur fertilizers in India like sulphur bentonite, gypsum, elemental sulphur and pyrite etc. Of all the inorganic sources of sulphur, gypsum is referred as one of the most economical and effective to pulse crops. Its interactions also showed synergistic and antagonistic effects with other nutrients. Moreover, sulphur is also available in association with the other nutrients like N (ammonium phosphate and ammonium sulphate) P, (SSP) K, (potassium sulphate and potassium magnesium sulphate) and zinc sulphate. The demand for optimum crop yield can be achieved by optimizing the availability of sulphur in required amounts. Hence to strengthen the production of pulses S may be recognized as a key element thereby making it a part of nutrient management.

Conflict of interest

The authors declare that they have no conflict of interest.

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