The Pharma Innovation Journal 2022; SP-11(7): 2127-2131

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(7): 2127-2131

www.thepharmajournal.com
Received: 09-05-2022
Accepted: 12-06-2022

Vipul Kumar Rawal
Department of Agronomy,
School of Agriculture
Lovely Professional University,
Jalandhar, Punjab, India

Corresponding Author
Vipul Kumar Rawal
Department of Agronomy,
School of Agriculture
Lovely Professional University,
Jalandhar, Punjab, India

Role of sulphur in legume crops

Vipul Kumar Rawal

Abstract
Legumes are regarded as a very good source of proteins to humans as well as animals. Legumes help in achieving the goals of food security in India by providing rid of malnutrition, hunger, starvation, etc. because of their protein value. Along with proteins, various vitamins and other micronutrients and macronutrients are present in the legumes which fulfil the nutritional requirement. Legumes like chickpea, lentils, soybean, mung bean, and groundnut, etc. are the plants that help in the biological nitrogen fixation of the nitrogen. So, the plant which helps in biological nitrogen fixation suffered from the deficiencies of sulphur, phosphorus, and potassium, etc. Due to the lack of all these macronutrients, the biological nitrogen fixation got affected and directly affects the host plant. Even the year 2016 is also regarded as the international year of pulses mainly the grain legumes. Leguminous crops contain leguminous bacteria in their nodules which helps in fixing nitrogen. The sulphur oxidizing bacteria is important for the leguminous crop because it maintains the amount of sulphur in soil along with this it also fulfils the nitrogen requirement. The sulphur oxidizing bacteria maintain the symbiotic nitrogen fixation in legumes and therefore maintain the yield. This review paper discusses the importance of leguminous crops in food security for future perspective, importance, and role of sulphur in leguminous crops by improving the soil health and environment. So, the application of bio fertilizers and mainly the sulphur oxidizing bacteria is important to increase production.

Keywords: Bacteria, fixation, legumes, nitrogen, proteins, sulphur, symbiotic

Introduction
Sulphur is a chemical element represented by symbol S. there are many elements are found in the earth's crust along with them sulphur is one of them. The atomic no. of sulphur is 16, found in abundance in nature and non-metallic. The chemical formula of sulphur in the form of octatomic molecules is S8 under normal conditions. If we talk about its physical appearance, sulphur is in bright yellow, and at room temperature at crystalline form. In the whole universe, sulphur comes in the tenth number, on earth, it comes in 5th no. as the most common element. Mostly it is found in the form of sulphide and sulphate minerals. It is found in abundant form so its uses were popular in ancient India, Greece, Egypt, and China. Sulphur was also known as 'brimstone' in previous times which means burning stone (Wikipedia, 2021) [29]. By removing sulphur containing products from natural gas and petroleum elemental sulphur is produced, the most common use of sulphur in the agriculture field is to extract the sulphuric acid for sulphate and phosphate fertilizer, etc. along with this it is also used for a matchstick, insecticides, and fungicides. In some products organosulphur is there due to which pungent smell of natural gas, skunk scent, grapefruit, and garlic is there. The smell of rotting eggs and other biological processes is also due to hydrogen sulphide. It is a most common and important element and various forms are there of sulphur but the most common form is organosulphur and metal sulphides. There is a total of 3 amino acids (cysteine, cysteine, and methionine), two vitamins (biotin and thiamine), these are compounds of organosulphur (Wikipedia, 2021) [29]. There is another co-factor that consists of sulfur i.e. glutathione, thioredoxin, and iron-sulfur proteins. For the functioning of biochemical sulphur is the most common element and comes under macronutrient. If we talk about sulphur role in the agriculture field. As we all know plant's growth and development depend upon the availability of nutrients. There are 3 major nutrients i.e. nitrogen, phosphorus, and potassium (NPK) and along with these other nutrients are also important for plants in a small quantity known as micronutrient and sulphur is also the one nutrient among all which comes under macronutrient as it is applied in soil same quantity as nitrogen it can also be called 4th macronutrient (Wikipedia, 2021) [29]. Legumes are a very good source of proteins in India. In India, legumes are very cheap as compared to other protein sources so people opted for legumes as a good and cheapest source of proteins. Instead of proteins legumes also provide a good source of vitamins like B1 (Thiamine), B2 (Riboflavin),

B3 (Niacin), B6 (Pyridoxine), and B9 (Folic acid), etc. in the human diet (Anderson A.J & Spencer, D., 1950). After processing the raw material of legumes, they can be consumed as food. Legumes or leguminous crops include soybean, lentil, chickpea, pigeon pea, pea, black gram, green gram, mung bean, cowpea, peanut, and beans, etc. (Vidyalakshmi *et al*., 2009) [28]. The major advantage of leguminous crops is that help in nitrogen fixation. The leguminous crop can naturally fix nitrogen as the roots of the plants contains leguminous bacteria like rhizobium. Rhizobium can fix atmospheric nitrogen and provide a sufficient amount of nitrogen to the crop plants and the associated crops (Andrew, C. S., 1977) [2]. The cropping of non-leguminous crops with the leguminous crops can help in decreasing the use of chemical fertilizers because the legumes can symbiotically associate the nitrogen which also helps the associated crops (Tiwari *et al*., 1985) [27].

Importance of sulphur in crop production

SULPHUR is the element which contributes to the formation of protein and among all the nutrients it comes in 9th number along with sulphur plays an important role in the production of sugar in sweet corn. Due to weathering, organic matter, and the activity of microorganisms sulphur concentration can be affected in soil. In India, sulphur is deficient more than 41% as the soil is the major supplier of sulphur to plants. For plant's growth and development, sulphur is very important as it helps in the formation of proteins, enzymes, vitamins, and chlorophyll, and also in nodule formation and nitrogen fixation sulphur plays an important role as shown in (figure 1). A large no. of sulphur is needed for the synthesis of protein and oil formation in seeds. In the process of photosynthesis, sulphur is required but sulphur is generally required by the leguminous crop (alfalfa, clover, and soybean).

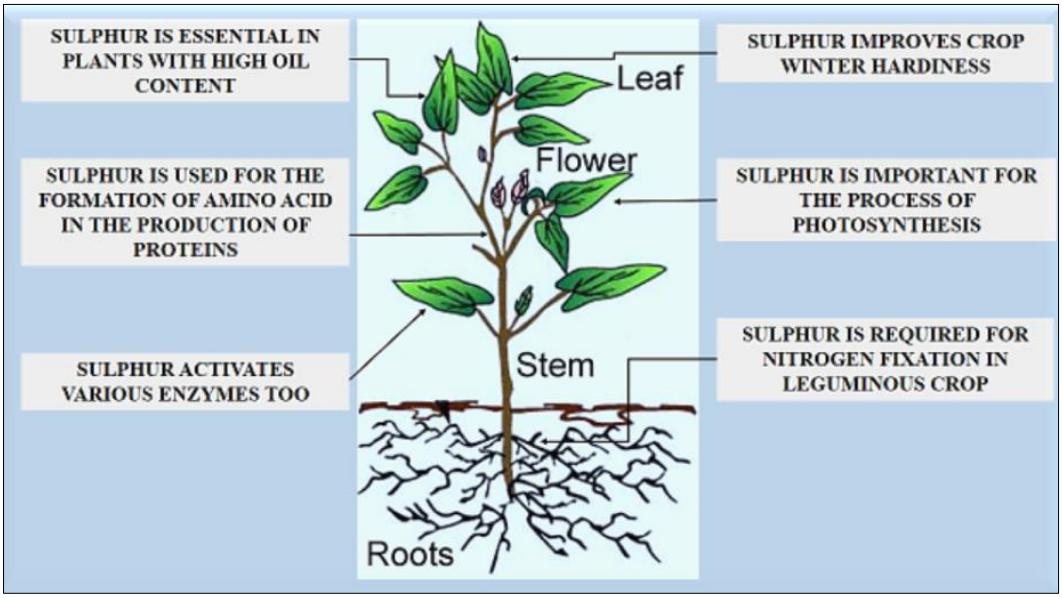

Fig 1: Role of sulphur in crop production

Reference: Prepared by author

Sulphur is a very important nutrient which helps in plant growth and development and is also resistant to plant from various biotic and abiotic stress. The food quality is affected strongly by the sulphur content present in it, in plants there are sulphate transport proteins that distribute and uptake the sulphur, and there is a total of 14 members in sulphate transport gene family (Becana *et al*., 2018) [3]. According to their cellular and subcellular expression, they are distinguished into 5 different groups among them first is sulphate transporters which work as a transporter and distributors of sulphate by the roots to a whole part of the plant, second group is usually for the loading and unloading of vascular sulphate, and the third group is for exchange of vascular sulphate other 2 group works is not much categorized. The plant sulphur status directly controls the 1, 2, and 4th group of sulphate transporter genes along with uptake and distribution of sulphur. The signaling and control of various transporter of sulphate are evaluated by cysteine and glutathione which is the product of sulphate assimilation (Sahota T. S. 2006) [19]. The sulphur uptake and distribution depend upon the requirement of sulphur for the growth of shoot and root, various stages of development i.e. vegetative growth, primary and secondary growth, production of fruit and seed it varies between the species and their structure and function. The growth rate of the plant, a requirement of sulphur and uptake is estimated by different parameters like; the large no. of sulphur is when uptake by sulphur transporter they are reduced and metabolized into organic compounds which are consumed by different parts of the plant for proper structural growth as the sulphur which is left out are consumed by the tissue and delivered into the vacuoles of the plant (Zhao *et al*., 2008) [31]. Reduction of sulphate takes place in the chloroplast along this root also can reduce sulphate. When the nitrate reduction takes place along with this sulphate reduction is also initiated in most of the herbaceous plants and the ratio is 2 to 6 in the root as a whole plant proportion. The sulphate is activated by the ATP to APS, and before it is reduced to sulphite it is catalyzed by the APS (Scherer H. W., 2001) [21]. However, by the action of sulphide reductase, sulphite is reduced to sulphide by the action of ferredoxin (reductant). In roots, the reduced form of sulphur is present which is transported in the form of methionine and to the shoot, it is transported in the form of cysteine and glutathione (Scherer H. W., 2001) [21]. Due to their specific features, the distribution of sulphur is a little more complex in an herbaceous plant (Scherer H. W., 2001) [21]. There are large trunks are present in trees where all the storage takes place, as

there is a very long route between the roots uptake and consumption as the long life span of trees are justified according to seasonal changes and storage of sulphur. In plants for the synthesis of methionine sulphur is important which is donated by the cysteine. In the tissue of the plant, there is the predominant proportion of organic sulphur is present in the form of cysteine and methionine, which contributes up to 60% and 90% as the total organic sulphur fraction (Schnug *et al*., 1993) [24]. The amino acids which include sulphur have significance in the structure and function of proteins and enzymes. In crops, there is a huge requirement of sulphur but majorly Brassica crops required more sulphur 1.5-2.2kmol/ha, followed by leek and onion 1 to 1.2kmol/ha, but in cereal crops, the requirement is up to 0.3 to 0.6kmol/ha (Schnug *et al*., 1993) [24]. The synthesis of secondary metabolites which contain sulphur is the reason there is a high requirement of sulphur in Brassica and allium crops (Schnug *et al*., 1993) [24]. The requirement of sulphur depends on the yield of a crop, if the crop is high yielding then it will need more nutrients which includes sulphur too. in plants sometimes we can see the deficiency of sulphur, it occurs when the crops do not get a sufficient amount of sulphur from the environment as it has been recorded in crops sulphur is more deficient (Jamal *et al*., 2010) [10]. If the crop is deficient then it will utilize the nitrogen inefficiently which leads to loss of nitrogen in the environment (Hawkesford *et al*., 2006) [8]. If we take an example in research of 2000 it was shown that the nitrate leaching was reduced by the application of sulphur. Therefore, it is concluded that if we correct the deficiency of sulphur then indirectly environment is benefit along with yield, and we can correct this deficiency by application of elemental sulphur (Hawkesford *et al*., 2006) [8]. The uptake in plant sulphate is in the readily available form and very mobile in neutral and alkaline soil due to which sudden leaching loss occurs during rainfall by the process of evapotranspiration (Hemesh *et al*., 2020) [9]. The elemental sulphur is first converted into sulphate then after it is available to plants, as sulphate fertilizer is preferred rather than elemental sulphur. If we talk about the origin of sulphur, the sulphur origin can be from weathering of rocks, organic sulphur mineralization, or groundwater (Skwierawska *et al*., 2016) [25].

Role of sulphur and its metabolism in legume crop

With the increase in population nowadays the food supply also increases and farmers are focusing in growing the cereals crops due to which the leguminous crops got negligence. In research areas also the research on legumes is very less so that the focus on genetic improvement is also less due to which the nutrients like nitrogen, phosphorus, potassium, and sulphur, etc. are depleting in Indian soils (Chaudhary *et al*., 2020) [4]. Sulphur is one of the important macro-nutrient and works as a coenzyme for most of the metabolites. The deficiency of sulphur in legumes and non-leguminous crops affects plant growth and development, physiological processes like photosynthesis and transpiration, etc. (Stamford *et al*., 2002) [26] due to which the yield of the crop is affected. The sulphur is directly related to nitrogen so the application of sulphur in the soil or crop also increases the amount of nitrogen in the soil (Divito, G.A & Sadras. V.O., 2014) [6]. In non-leguminous crops, the application of sulphur fertilizers and helps in fixing nitrogen in the soil. Nowadays the need for sulphur is increasing day by day but in the atmosphere, the amount of sulphur is very less whereas in the other layers like the hydrosphere and pedosphere the amount is high as compared to the atmosphere (Glowacka *et al*., 2019). In soils, the deficiency of sulphur is decreasing day by day. There are many reasons for the declining rate of sulphur in soils like the use of sulphur-free fertilizers, organic manures which contains very less amount of sulphur, and inappropriate use of chemical fertilizers or the sulphur free fertilizers (Poonia. S., 2019) [16]. Sulphur is also present in the soil but that for of sulphur is not easily available to the plants because of its presence in bounded form. The biofertilizers or the microbes which contain sulphur are regarded best for plant growth and are environmentally friendly (Kudi *et al*., 2018) [11]. The legumes are consumed in many ways by human beings like pulses, flour, dried pulses, and processed food, etc. The micronutrients like Calcium, Zinc, Iron, Phosphorus, Potassium, Magnesium, and Selenium, etc. are also present in the legumes so that they are a very good source of trace elements (Schnug. E & Haneklaus.S., 1998) [23]. Legumes are very good for animals also as they provide a very good source of nutrients (Ludecke, T.E., 1965) [13]. The leguminous fodder crops are Alfalfa, cowpea, clover, soybean, and lupin, etc. The crops like soybean and peanut have higher oil content and provide 35-40% of oil content. The crops like lupin can interact with the metal ions and work as a carrier for absorption (Scherer, H.W & Lange.A., 1996) [22]. Sulphur in the soil is applied in many forms like sulphur can also be applied with potassium and nitrogen which are easily soluble in water. There are many forms of sulphur like soluble form, insoluble form, elemental form, etc. In soils, the sulphur is present in soluble form (Oke, O.L., 1969) [15]. In elemental sulphur, before getting available to the plants the sulphur gets oxidized from its original form to sulphates and then available to plants but its uptake is very slow due to which it also shows residual effects. In this type of form of sulphur, mineralization occurs with the help of micro-organisms (Rathi *et al*., 2009) [18].

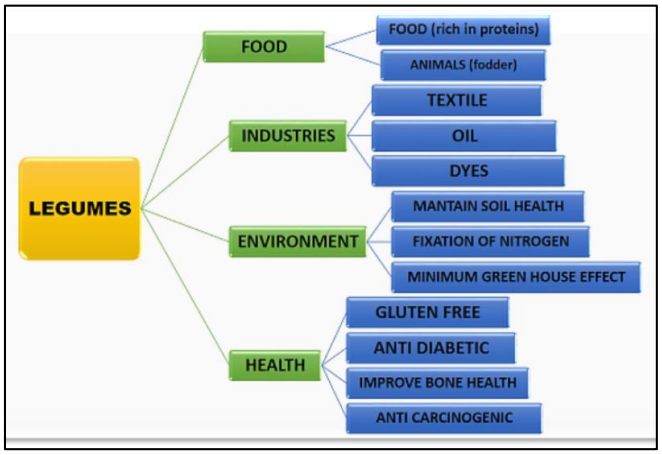

Fig 2: Importance of legumes

Reference: Prepared by authors

The leguminous crops help in the biological nitrogen fixation of nitrogen as shown in (figure 2). The biological nitrogen fixation of nitrogen results best than the application of nitrogen fertilizers. This type of nitrogen fixation reduces the contamination of soil and water, reduces the leaching effect of nutrients from the soil (Probert *et al*., 1977) [17]. The biological nitrogen fixation helps in increasing the yield of crops by opting for crop rotation techniques in non-leguminous crops. Biological nitrogen fixation also helps in

reducing stress conditions. Nitrogen is regarded as the most limiting nutrient for plants. After Nitrogen, Phosphorus is next in terms of limiting nutrients. About 35- 40% of crop yield is limited by the availability of phosphorus in the soil (Kudi *et al*., 2018) [11]. For the proper availability of phosphorus in the soil, biological nitrogen fixation bacteria are used. The leguminous rhizobia respond towards the nutrients like phosphorus and potassium because these nutrients are found deficient in soils. The application of sulphur with biological nitrogen-fixing bacteria is not much popular because the nutrient sulphur is deficient in Indian soils (Chaudhary *et al*., 2020) [4]. The deficiency of sulphur is repeatedly increasing because of the depletion of sulphur in agricultural soils. The leguminous crops which need nitrogen through the biological nitrogen-fixing bacteria also require a high amount of macronutrients like phosphorus, sulphur, and potassium, etc. so that the nitrogen can get available to the soil (Andrew, C.S., 1977) [2]. All these nutrients if not properly available to the soil, then they also affect the biological nitrogen-fixing bacteria, and the root growth, nodule growth, its formation, and working also get affected. As the macronutrient phosphorus is important for root and nodule development, synthesis of membranes, transferring of signals, etc., a high amount of ATP is also required for the proper nitrogenase functioning (Tiwari *et al*., 1985) [27]. Potassium also plays a major role in the nodule synthesis, activation of enzymes, etc. The leghaemoglobin present in root nodules has a direct relationship with supply of sulphur. The deficiency of nitrogen directly triggers nodule growth (Poonia. S., 2019) [16].

As we already discussed earlier that sulphur is an important macronutrient and compound of amino acid. If there is a deficiency of sulphur in the legume then its growth and development will be stunted along with photosynthesis and yield. The legume crops required several amounts of sulphur (Skwierawska *et al*., 2016) [25]. If there is an appropriate supply of sulphur then there will be appropriate N2 fixation, and there will be a lower activity of nitrogenase if there will be a lower concentration of sulphur in soil (Skwierawska *et al*., 2016) [25]. Due to deficiency of sulphur in nodulated legumes then the crop will be affected by 3 types of problems i.e. decrease in nodulation, N2 fixation inhibition, and general alteration of nodule metabolism. In various legume plants, the deficiency system is visible like there is a decrease in the no. of nodule and mass/root length in white clover. Due to lower sulphur concentration, it directly targets the nitrogenase and metabolism of nodule. There is a decrease in the activity of nitrogenase if the plant is suffering from sulphur deficiency, due to the lower availability of cysteine and methionine (Nagaram I. P., 2020) [14]. There is a sufficient amount of leghemoglobin, glucose, ATP, and ferredoxin in nodules, but vice-versa if there is no sufficient amount of sulphur. The uptake of sulphate is done by the sulphate transporters but the first sulphate is reduced to organic sulphide (Devi *et al*., 2012) [5]. The sulphate assimilation is started with the activation of sulphate, as APS plays a very important role in the reduction of sulphite and sulphide (Devi *et al*., 2012) [5].

The question arises of how sulphur helps in nitrogen fixation in leguminous crops. As we all know that in legume crops there is a process called nitrogen fixation which occurs between roots of plant and rhizobia bacteria, they both made a symbiotic relationship with each other. In the roots of plant rhizobia, bacteria inhibit and exude the nitrogenase by which the N2 (atmospheric nitrogen) is converted into NH3 (plant-available ammonia) (Nagaram I. P., 2020) [14]. The converted nitrogen (ammonia) is readily absorbed by the plant and consumed by them for the production of amino acids, proteins, nucleic acids, and other compounds containing nitrogen. In exchange, photosynthate is received by rhizobia (Zhao *et al*., 1999) [30]. In a natural ecosystem, the crops can produce up to 25 to 75lb of nitrogen/acre/year by the relationship between legumes and rhizobia. There is a high demand for sulphur in nodulated legumes as sulphur plays an important role in nitrogen fixation by promoting the nodule formation in pulse there is a deficiency of sulphur due to a small and low number of nodules, and we know if nodules are suffering from sulphur deficiency then they contain less leghemoglobin, glucose, ATP (Saleem *et al*., 2019) [20]. By application of sulphur the concentration of these will increase in the nodules and nitrogen fixation will take place (Nagaram I. P., 2020) [14]. Another function of sulphur is it supports the symbiotic nitrogen fixation, as we know for nitrogenase sulphur is the key ingredient. The nodules which are suffering from sulphur deficiency then their nitrogenase rate will also decrease as a result there will be a decrease in the process of conversion of nitrogen to an available form of nitrogen (nitrate) (Saleem *et al*., 2019) [20]. There is a key component in a plant called ferredoxin which is a very important component for photosynthesis and nitrogen and fixation and sulphur is the key component of ferredoxin, and this enzyme is useful in the process called assimilation of nitrogen, not only this sulphur also enhance the formation of a nodule. Sulphur helps in the uptake and transportation of various enzymes and nutrients which are important for the production of proteins and chlorophyll and increase the efficiency of the plant to use nitrogen (Saleem *et al*., 2019) [20].

Conclusion

The legumes crops are well suited for the areas where nitrogen is deficient because they provide a sufficient amount of nitrogen to the crop plants. The leguminous crop contains nodules in their roots which helps in the fixation of nitrogen. The leguminous bacteria which is present in the root nodules of the legume crops fix the atmospheric nitrogen. The application of sulphur oxidizing bacteria or sulphur fertilizers in leguminous crops can also provide additional nitrogen with sulphur. So, with the application of sulphur, additionally, nitrogen is also available to the legumes plants which directly helps in increasing the yield of the crop. The macronutrient sulphur plays an important role in the crops having high oil content because sulphur is the element that increases the amount of oil in oilseed crops like mustard, peanut, soybean, and sunflower, etc. Sulphur is also used as a precursor for many enzymes, for the activation of enzymes and various metabolic processes like photosynthesis, respiration, and evapotranspiration, etc. It helps in the formation of amino acids which further helps in the formation of proteins. During the winter season, sulphur improves the winter hardness of the crop. This review paper depicts that sulphur plays a major role in leguminous crops by providing an extra amount of nitrogen which is good for the crop plant. Thus, the importance of sulphur is very much in leguminous crops because it works as a key component for many enzymes and the leguminous crops serve as best for sulphur application.

Author contribution

Vipul Kumar Rawal & Dr. Sarvjeet Kukreja contributed equally to this work.

Acknowledgement
V.K.R and S.K gratefully acknowledge the support provided by Lovely Professional University, Jalandhar, Punjab.

Reference

1. Anderson AJ, Spencer D. Sulphur in nitrogen metabolism of legumes and non-legumes. Australian Journal of Biological Sciences. 1950;3(4):431-449.
2. Andrew CS. The effect of sulphur on the growth, sulphur and nitrogen concentrations, and critical sulphur concentrations of some tropical and temperate pasture legumes. Australian Journal of Agricultural Research. 1977;28(5):807-820.
3. Becana M, Wienkoop S, Matamoros MA. Sulfur transport and metabolism in legume root nodules. Frontiers in plant science. 2018;9:1434.
4. Chaudhary S. Dhanker R, Kumar R, Goyal S. Importance of Legumes and Role of Sulphur Oxidizing Bacteria for Their Production: A Review. Legume Research-An International Journal. 2020;1:10.
5. Devi KN, Singh LNK, Singh MS, Singh SB, Singh KK. Influence of sulphur and boron fertilization on yield, quality, nutrient uptake and economics of soybean (Glycine max) under upland conditions. Journal of Agricultural Science. 2012;4(4):1.
6. Divito GA, Sadras VO. How do phosphorus, potassium and sulphur affect plant growth and biological nitrogen fixation in crop and pasture legumes? A meta-analysis. Field Crops Research. 2014;156:161-171.
7. Głowacka A, Gruszecki T, Szostak B, Michałek S. The response of common bean to sulphur and molybdenum fertilization. International Journal of Agronomy, 2019.
8. Hawkesford MJ, De Kok LJ. Managing sulphur metabolism in plants. Plant, Cell & Environment. 2006;29(3):382-395.
9. Hemesh K, Brar BS. Role of sulphur in cereal crops: A review. Journal of Pharmacognosy and Phytochemistry. 2020;9(6):1864-1869.
10. Jamal A, Moon YS, Zainul Abdin M. Sulphur-a general overview and interaction with nitrogen. Australian Journal of Crop Science. 2010;4(7):523-529.
11. Kudi S, Swaroop N, David AA, Thomas T, Hasan A, Rao S. Effect of different levels of sulphur and zinc on soil health and yield of greengram (*Vigna radiata* L.) Var. Patidar-111. Journal of Pharmacognosy and Phytochemistry. 2018;7(3):2271-2274.
12. Lakkineni KC, Abrol YP. Sulphur Requirement of Rapeseed-Mustard, Groundnut and Wheat: A Comparative Assessment. Journal of Agronomy and Crop Science. 1992;169(4):281-285.
13. Ludecke TE. Further aspects of sulphur nutrition of legumes. In Proceedings of the New Zealand Grassland Association. 1965, January, 129-138.
14. Nagaram IP. A review on role of sulphur nutrition in oilseed crops. Journal of Pharmacognosy and Phytochemistry. 2020;9(6):1152-1156.
15. Oke OL. Sulphur nutrition of legumes. Experimental Agriculture. 1969;(2):111-116.
16. Poonia S. Studies on Alpha–Amylase Activity in Germinating Seeds of Four Leguminous Crops in Response to Sulphur Dioxide. Biotech Today: An International Journal of Biological Sciences. 2019;9(2):51-53.
17. Probert ME, Jones RK. The use of soil analysis for predicting the response to sulphur of pasture legumes in the Australian tropics. Soil Research. 1977;15(2):137-146.
18. Rathi BK, Jain AK, Kumar S, Panwar JDS. Response of Rhizobium inoculation with sulphur and micronutrients on yield and yield attributes of blackgram [*Vigna mungo* (L.) Hepper]. Legume Research-An International Journal. 2009;32(1):62-64.
19. Sahota TS. Importance of sulphur in crop production. Northwest Sci. 2006;9:10-12.
20. Saleem M, Elahi E, Gandahi AW, Bhatti SM, Ibrahim H. Ali M. Effect of Sulphur Application on Growth, Oil Content and Yield of Sunflower. Sarhad Journal of Agriculture, 2019, 35(4).
21. Scherer HW. Sulphur in crop production. European Journal of agronomy, 2001;14(2):81-111.
22. Scherer HW, Lange A. N 2 fixation and growth of legumes as affected by sulphur fertilization. Biology and Fertility of Soils. 1996;23(4):449-453.
23. Schnug E, Haneklaus S. Diagnosis of sulphur nutrition. In Sulphur in agroecosystems Springer, Dordrecht. 1998, 1-38.
24. Schnug E, Haneklaus S, Murphy D. Impact of sulphur fertilization on fertilizer nitrogen efficiency. Sulphur in Agriculture. 1993;17(8):12.
25. Skwierawska M, Benedycka Z, Jankowski K, Skwierawski A. Sulphur as a fertiliser component determining crop yield and quality. Journal of Elementology, 2016, 21(2).
26. Stamford NP, Freitas ADS, Ferraz DS, Santos CERS. Effect of sulphur inoculated with Thiobacillus on saline soils amendment and growth of cowpea and yam bean legumes. The Journal of Agricultural Science. 2002;139(3):275-281.
27. Tiwari KN, Dwivedi BS, Pathak AN. Iron pyrites as sulphur fertilizer for legumes. Plant and soil. 1985;86(2):295-298.
28. Vidyalakshmi R, Paranthaman R, Bhakyaraj R. Sulphur Oxidizing Bacteria and Pulse Nutrition- A Review. World Journal of Agricultural Sciences. 2009;5(3):270-278.
29. Wikipedia contributors. Sulfur. In Wikipedia, The Free Encyclopedia. Retrieved. 2021, October 28;12:40, October 31, 2021, from https://en.wikipedia.org/w/index.php?title=Sulfur&oldid=1052222597
30. Zhao FJ, Hawkesford MJ, McGrath SP. Sulphur assimilation and effects on yield and quality of wheat. Journal of cereal science. 1999;30(1):1-17.
31. Zhao FJ, Tausz M, De Kok LJ. Role of sulfur for plant production in agricultural and natural ecosystems. In Sulfur metabolism in phototrophic organisms. Springer, Dordrecht. 2008, 417-435.
32. Zhao FJ, Wood AP, McGrath SP. Effects of sulphur nutrition on growth and nitrogen fixation of pea (*Pisum sativum* L.). Plant and Soil. 1999;212(2):207-217.