**Original Research Article**

**Foliar Sulfur Application and Its Effects on Sulfur Distribution, Seed Yield, and Soil Fertility in Onion Seed Crop**

**Abstract**

This study examined the effects of different doses of foliar sulfur application on sulfur distribution in various plant parts, soil dynamics, and seed yield in onion seed crops. The research was conducted at the ICAR–Directorate of Onion and Garlic Research, Rajgurunagar, using a randomized complete block design with six treatment levels, including a control, where sulfur applications ranged from 0.2% to 1% across two growing seasons (2020–21 and 2021–22). This study showed that the increase in the levels of sulfur application led to higher concentration of sulfur in the leaf, stem, and bulb tissues with a maximum of 1.33% S in the leaf at 60 days after planting (DAP) in the 1% treatment. Chemical tests showed that there was an increase in the level of sulfur in the applied plots, with the available sulfur standing at 12.40 mg/kg at harvest. There was a positive trend between the levels of sulfur and seed yield where the highest seed yield of 920.00 g/plot was realized at 0.8% S during the 2021/2022 season. This calls for proper management of sulfur in onion seed production and the use of foliar application of sulfur in increasing the yield of the crop and improving the health of the soil. The outcomes are useful to the security of onion seed production.

**Keywords:** Sulfur, Soil dynamics**,** Seed, Onion**,** Plant tissues**,** Soil health

1. **Introduction**

Seeding is an important process in agriculture as it forms the basis of crop planting and has a bearing on the yield of crops. High-quality seeds guarantee that a high percentage of seeds will germinate, grow at the same rate, and be able to withstand harsh conditions of the environment. In the context of agricultural crops, the production of onion, scientifically known as *Allium cepa L.*, is economically important for food security at local and international levels. This helps to increase the yield of subsequent crops, but also to increase the demand for them in the market. Nutrients play a significant role in seed development most especially the Sulphur (S) since it influences the quality traits of the seed. Increasing the recommended dose of fertilizers (RDF) positively correlated with enhanced growth and yield, indicating that nutrient management is crucial for onion production (Kumawat *et al*., 2023).

Sulfur is a macronutrient that is vital for the metabolic processes in plants, especially in the synthesis of amino acids, proteins and chlorophyll chlorophylls (Hawkesford *et al*., 2023; Dawar *et al*., 2023). In regard to seed production, the role of sulfur in relation to metabolic pathways is highly important as it helps to produce strong seeds with higher nutritive values and germination percentages. It has been ascertained that sulfur shortage decreases the size of seeds and germination rates, which affects the establishment and production of crops (Zuber et *al.,* 2013). For instance, Barczak *et al.,* (2011) in their study observed that sulfur applications enhanced the seed quality parameters in mustard and the seeds were bigger. These findings have clearly shown that sulfur nutrient is not only essential for the vegetative growth of the crops but also plays a vital role in the seed yield of different crops.

The use of sulfur fertilizer by foliar spray can be recommended as an effective way of increasing the availability and uptake of sulfur in crops. This fertilizer is in a soluble form of sulfur and is particularly suitable for application on the foliage of plants so that it can easily be absorbed and used by the plant (Latha & Nadanassababady, 2003). Literature has also revealed that foliar application of sulfur fertilizer can boost the content of sulfur in tissues of plants, thereby increasing the quality of seeds and yield. Bhat *et al*. (2017) also observed that the application of sulfur fertilizer significantly enhanced the levels of sulfur in the leaves of cabbage and enhanced seed yield.

Also, the changes in the soil characteristics after the application of sulfur fertilizer are important in determining the nutrient uptake processes. Sulfur fertilizer contributes to altering soil pH, improving the physical structure of the soil as well as the availability of nutrients that is vital in root growth and nutrient uptake (Kılıç & Sönmez, 2025). Rezapour (2014) also conducted a study that revealed that the application of sulfur fertilizer enhanced the conductivity of the soil in regard to sulfur uptake by plants.

In Summary, sulfur enhances the seed production of onions and their quality, thus playing an important role in the production process. The purpose of this research is to determine the effectiveness of different sulfur foliar sprays on the absorption of sulfur in onion seed crops with reference to the soil and the consequent seed yield. In this regard, the research will compare the impact of the various treatments on the availability and uptake of sulfur in the onion seeds. Also, the impact that sulfur has on the soil and the nutrients in it will be investigated after the application of the treatment. In conclusion, this study aims to identify the best approaches that should be followed when applying sulfur to onion seed production so as to create sustainable agriculture and improve the quality and quantity of seeds.

1. **Materials and Methods**
2. ***Study Area***

The experiment was carried out in the field of the ICAR – Directorate of Onion and Garlic Research, Rajgurunagar in the onion growing season of 2020 and 2021. The sulfur content in the experimental field ranged from 11.48 mg/kg in the year 2020– 2021 to 12.50 mg/kg in the year 2021– 2022. The soil type was clay loam and the pH of the soil was 7.9 which showed that the growth conditions of onion were alkaline.

1. ***Experimental Design***

In this study, the complete randomized block design (CRBD) was used to analyze the impact of six treatments: control, 0.2%, 0.4%, 0.6%, 0.8%, and 1% sulfur foliar applications. The experiment was conducted in such a way that each treatment had five replications and the area covered was 16.8 square meters per plot. The bulbs were planted for seed production using the ridges and furrows method, with a row spacing of 60 cm and a plant spacing of 20 cm, total of 120 bulbs planted per treatment.

1. ***Plant Material***

The variety of onion bulbs used in this study was Bhima Shakti, characterized by a bulb size of 45–60 mm in diameter, were sourced from the Seed Unit of ICAR- Directorate of Onion and Garlic Research, Pune, India and were treated accordingly to ensure uniform field emergence.

1. ***Fertilization Regimen***

The experiment was laid out in a Completely Randomized Block Design (CRBD). A basal dose of 250 g of NPK (10:26:26) and 122 g of sulfur was applied to all sulfur-treated plots. Foliar sprays of sulfur were administered treatment-wise at concentrations of 0.2% (T2), 0.4% (T3), 0.6% (T4), 0.8% (T5), and 1.0% (T6) applied in three split doses at 30, 45, and 60 days after planting. For the control treatment (T1), only the basal dose comprising 855 grams of single super phosphate (SSP), 228 grams of muriate of potash (MOP), and 91 grams of sulfur was applied with.

1. ***Sulfur Uptake and Distribution***

Total sulfur content in leaves, stems, and bulbs was determined using the turbidimetric method outlined by Jackson (1967). A sample of 0.5 g from each plant part was dried and ground to a fine powder. The ground samples were decomposed using a solution of nitric acid and perchloric acid so as to make sulfur soluble. After digestion, the solutions were allowed to cool and then filtered in order to remove all the undissolved particles. Barium chloride solution was then added to each of the filtered solutions to form barium sulfate (BaSO₄). The turbidity of the suspension was determined spectrophotometrically at 420 nm in order to determine the concentration of sulfur. To make the determination accurate, calibration standards were made from known sulfur concentrations in order to create the curve. Data was taken on the total sulfur percentage in the leaf samples and stem samples and bulbs at 30 and 60 days after planting. All results were given in mg S/kg of dry plant material, which gave information about the sulfur content that is important for plant nutrient and growth assessment.

1. ***Soil Sulfur Assessment***

Sediments were taken at two times: before planting and after harvesting using systematic random sampling technique that would enable the taking of random samples from the population. The samples collected were air-dried and then sieved through 2 mm mesh size, 10 grams of each soil sample was weighed and mixed with 100 mL of 0.15 M calcium chloride (CaCl2) solution in a 250 mL Erlenmeyer flask as described by Jackson (1967). The mixture was shaken for one hour with a view to extracting the desired compounds, then allowed to settle for a period of 10minutes and thereafter filtered through Whatman no. 1 filter paper to get a clear extract. The filtered solution was also analyzed for sulfur concentration by inductively coupled plasma ICP spectroscopy, calibration standards being prepared for the purpose. The results were given in kg/ha, which gave a reasonable measure of the amount of sulfur that is available in the soil and can be taken up by the plants, which is important in evaluating the fertility status of the soil and in formulating the nutrient management plan.

1. ***Statistical Analysis***

Thereafter, the analytical values that were obtained were analyzed statistically using statistical analytical system software. It also involved use of ANOVA to compare the treatment means so as to establish the differences in the effects of various sulfur treatments on sulfur uptake and seed yield in onion seed production.

1. **Result**
2. ***Total Sulfur Content Percentage in Leaf Sample***

The total sulfur percentage in leaf samples was assessed at 30 and 60 days after planting (DAP) during the 2020–21 and 2021–22 growing seasons. At 30 days after planting, the differences among treatments were found to be non-significant in both years. Significant differences were observed at 60 days after planting. In 2020–21, sulfur content increased from 0.24% in the control to 0.93% in the 1% sulfur treatment, with higher sulfur accumulation recorded at increasing sulfur levels. In 2021–22, sulfur content ranged from 0.76% in the control to 1.33%, with 0.8% statistically at par with 1% sulfur applications. The sulfur treatments at 0.4%, 0.6%, 0.8%, and 1% were statistically at par, while the control and 0.2% treatments recorded significantly lower sulfur content as presented in Table 1.

1. ***Total Sulfur Content in Stem Samples***

The total sulfur percentage in stem samples was recorded at 30 and 60 days after planting (DAP) during the 2020–21 and 2021–22 growing seasons. At 30 days after planting, differences among treatments were found to be non-significant in both years. At 60 days after planting, significant variations were observed. In 2020–21, sulfur content increased from 0.17% in the control to 0.44% under the 1% sulfur treatment. In 2021–22, sulfur content ranged from 0.83% in the control to 1.36% under the 0.6% sulfur application. An overall increasing trend in sulfur content was observed with higher sulfur application rates, as summarized in Table 1.

***3.3 Total Sulfur Content in Bulb Sample***

The total sulfur percentage in bulb samples was recorded at 30 and 60 days after planting (DAP) during the 2020–21 and 2021–22 growing seasons. At 30 days after planting, significant differences among treatments were observed in both years. In 2020–21, sulfur content increased from 0.30% in the control to 0.88% under the 1% sulfur application. In 2021–22, sulfur content ranged from 0.55% in the control to 0.95% in the 1% sulfur treatment. At 60 days after planting, similar significant variations were recorded. In 2020–21, sulfur content increased from 0.42% in the control to 1.39% under 1% sulfur application. In 2021–22, sulfur accumulation improved from 0.82% in the control to 1.66% under the 1% treatment. An overall increase in sulfur accumulation was observed with higher sulfur application levels, as presented in Table 1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table. No. 1. Total Sulphur percentage of leaf, stem and bulb at 30 and 60 days after planting.** | | | | |
|  | **Thirty days** | | **Sixty days** | |
| **Treatments** | **2020–21** | **2021–22** | **2020–21** | **2021–22** |
| **Leaf** |  |  |  |  |
| **Control** | 0.94 | 1.42 | 0.24 | 0.76 |
| **Sulphur at 0.2%** | 0.95 | 1.75 | 0.66 | 0.98 |
| **Sulphur at 0.4%** | 0.97 | 1.64 | 0.35 | 1.27 |
| **Sulphur at 0.6%** | 0.77 | 1.83 | 0.82 | 1.23 |
| **Sulphur at 0.8%** | 0.97 | 1.70 | 0.75 | 1.33 |
| **Sulphur at 1%** | 1.26 | 2.04 | 0.93 | 1.33 |
| **Gen. Mean** | **0.98** | **1.73** | **0.63** | **1.15** |
| **C.D. 5%** | NS | NS | 0.14 | 0.18 |
| **Stem** |  |  |  |  |
| **Control** | 0.26 | 0.66 | 0.17 | 0.83 |
| **Sulphur at 0.2%** | 0.27 | 0.67 | 0.22 | 0.73 |
| **Sulphur at 0.4%** | 0.27 | 0.71 | 0.19 | 0.95 |
| **Sulphur at 0.6%** | 0.35 | 0.77 | 0 .29 | 1.36 |
| **Sulphur at 0.8%** | 0.35 | 0.89 | 0.35 | 1.23 |
| **Sulphur at 1%** | 0.3 | 0.82 | 0.44 | 1.16 |
| **Gen. Mean** | **0.31** | **0.75** | **0.28** | **1.04** |
| **C.D. 5%** | NS | NS | 0.15 | 0.30 |
| **Bulb** |  |  |  |  |
| **Control** | 0.30 | 0.55 | 0.42 | 0.82 |
| **Sulphur at 0.2%** | 0.40 | 0.60 | 0.69 | 0.98 |
| **Sulphur at 0.4%** | 0.49 | 0.68 | 0.72 | 0.79 |
| **Sulphur at 0.6%** | 0.74 | 0.94 | 1.07 | 1.12 |
| **Sulphur at 0.8%** | 0.81 | **0.74** | **1.21** | **1.26** |
| **Sulphur at 1%** | 0.88 | 0.95 | 1.39 | 1.66 |
| **Gen. Mean** | **0.32** | **1.03** | **0.23** | 1.11 |
| **C.D. 5%** | 0.11 | 0.15 | 0.93 | 0.14 |

*\*Means with different letters in the same column are statistically significant based on Duncan’s multiple range test (p ≤ 0.05)*

1. ***Available Soil Sulfur Levels***

The available sulfur content in the soil before planting was 11.48 mg/kg in 2020–21 and 12.50 mg/kg in 2021–22. After harvesting, soil sulfur content ranged from 4.83 mg/kg in the control to 12.40 mg/kg under the 1% sulfur treatment during 2020–21. In 2021–22, available sulfur content varied from 5.43 mg/kg in the control to 12.27 mg/kg under the 0.8% sulfur application. An overall increase in available soil sulfur was observed with higher levels of sulfur application, as summarized in Fig 1.

**Fig 1.** Available soil Sulphur after harvesting (mg/kg) data are statistically significant based on Duncan’s multiple range test (*p ≤ 0.05*)

1. ***Total Seed Yield per Plot***

The seed yield per plot was recorded under different sulfur treatments during the 2020–21 and 2021–22 growing seasons. In 2020–21, seed yield ranged from 515.17 g per plot under the 0.2% sulfur treatment to 603.67 g per plot under the 1% sulfur application. In 2021–22, seed yield varied from 766.67 g per plot in the control to 920.00 g per plot under the 0.8% sulfur treatment. These results highlight the positive role of foliar sulfur applications in increasing seed yield, as summarized in Fig 2.

**Fig 2.** Effect of different doses of Sulphur on seed yield per plot (gm) data are statistically significant based on Duncan’s multiple range test (*p ≤ 0.05*)

1. **Discussion**

The findings of this study are very useful in understanding the uptake and distribution of sulfur (S) in onion seed production and the effects that sulfur fertilization has on various phases of crop germination, seed yield, and soil health. These dynamics are critical in the management of fertilization in order to improve the seed yield of onion crops (*Allium cepa* L.).

1. ***Sulfur Uptake Patterns in Onion Seed Production***

This study also revealed that the accumulation of sulfur in the onion seed production was in a higher amount in the form of S because the higher dosage of S was observed in the leaf, stem and bulb tissues. For instance, in the 2021/2022 growing season, the highest rate of 1% sulfur gave the highest content of 2.04% sulfur in the leaves at 30 DAP compared to 1.42% in the control. The same was also observed by Bhat *et al*. (2017) who noted that the application of sulfur enhanced the level of sulfur in the cabbage and therefore the overall efficiency of the sources of sulfur in various crops. Another study by Mishra *et al*. (2013) also showed that sulfur content in oilseed crops was directly related to the sulfur applied to crops and they concluded that sulfur was vital in metabolic activities that were needed in seed formation.

1. ***Soil Sulfur Dynamics and Implications for Seed Production***

It further explains the changes in the concentration of sulfur in the soil after the application and shows that, apart from the sulfur nutrient value, the treatments improve the quality of the soil. In the first measurements of the soil, the amount of sulfur was not uniform with 0.2% of sulfur yielding the highest results. The results of the post-harvest analysis showed that sulfur levels were higher in treated plots than in control plots, as confirmed by Rezapour (2014) who established that sulfur enhanced physical properties of saline-alkaline soils through improvement of nutrient retention. Similarly, Ahmed *et al*. (2016) also revealed that sulfur decreased sodium content in the saline soils and subsequently increased nutrient uptake and crop productivity. These are important in increasing the nutrient retention capacity of the soils, which is of great importance in the production of onion seeds especially in areas that lack sulfur.

1. ***Seed Yield and Sulfur Fertilization***

This shows that the application of sulfur is effective in boosting the seed yield by a huge proportion. In both growing seasons, there is a significant increase in the number of seeds per plot with the higher sulfur dosages where the 0.4% sulfur yielded the highest of 920 gm in the 2021– 2022 growing season. This is in line with *Barczak et al* (2011) who noted that increased sulfur improved seed quality in the mustard crop. Moreover, the study by Zuber *et al.* 2013 established that adequate sulfur nutrition enhanced seed size and vigor in oilseed crops, thus supporting the assertion on the role of sulfur on seed quality.

1. ***Implications for Fertilization Strategies in Onion Seed Production***

The research findings offer critical implications about how onion seed production should approach fertilizer applications. This practice shows promise for standard fertilization methods because sulfur treatments enhance soil health and provide better seed quality and yield outcomes. The findings have direct application in areas where soil sulfur content is low because conventional fertilizer methods prove insufficient. The research conducted by Hadole *et al*. (2024) demonstrated that sulfur-treated crops absorbed nutrients more effectively while producing greater yields than conventional fertilizer-treated crops. Farmers who use targeted sulfur applications for management purposes achieve optimal nutrient efficiency while supporting sustainable agricultural practices and better onion productivity (Bruulsema & Olson, 2024).

1. **Conclusion:**

This paper is on the role of sulfur fertilizer in increasing the yield of onion seed crop. The use of sulfur on the foliage enhanced the uptake of sulfur in the plant tissues, and thereby increased seed yield and soil quality. The findings show that split-dose sulfur applications are effective in increasing nutrient uptake during the development stages. These are the guidelines for sustainable production of onion seeds and these show a clear indication that there is need for more research on how sulfur impacts on the soils and yields in the long run.

**Declaration of competing interest**

The authors declare that have no conflict of interest.

**Data availability**

Data will be made available on request.

**CRediT authorship contribution statement**

Indrajitsingh Pravinsingh Girase: Writing - original draft, Methodology, Investigation, Data curation. Prashant Kumar Rai: Writing - review & editing original draft, Investigation, Data curation. Vaidurya Pratap Sahi: Writing - review & editing. Arunachalam Thangasamy: Investigation, Resources, Methodology. Prashant Ankur Jain: Investigation. Vishwanath Rohidas Yalamalle: Conceptualization, Project administration, Resources, original draft, Writing - review & editing, Investigation.

**Disclaimer (Artificial Intelligence)**

The author hereby declare that no generative AI technologies, including large language models (such as ChatGPT, Copilot, etc.) or text-to-image generators, were used during the writing, editing, or preparation of this manuscript. All content is the result of the author original work, based on their own expertise, interpretation of data, and literature review.

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