Environment and Ecology 43 (1A) : 349—354, January—March 2025
Article DOI: https://doi.org/10.60151/envec/BFFI6744
ISSN 0970-0420

Synergistic Effect of Elemental Sulfur Doses and Micronutrient Foliar Application on Growth and Yield of *Glycine max* L. (Soybean)

Heena A. Magodia, Pooja V. Jagasia, Archana P. Kale

Received 7 February 2025, Accepted 14 March 2025, Published on 17 March 2025

ABSTRACT

Soybeans, which are rich in protein, are a major crop for producing edible oil and animal feed. Sustainable soybean production in India faces challenges primarily due to insufficient nutrient management. This study, conducted in the premises of Rashtriya Chemicals and Fertilizers, Mumbai, Maharashtra, assessed the impact of varying sulfur doses combined with the recommended dose of fertilizers (RDF) and micronutrient foliar spray (Cu 1.0%, Zn 3.0%, Mn 1.0%, Fe 2.5%, B 0.5%, Mo 0.1%) on the growth and yield of *Glycine max* L. six treatment combinations (T1-T6) in four replicates, the study evaluated RDF alone, RDF with three sulfur doses (15, 30, and 45 kg/ha) plus micronutrients, RDF with sulfur (45 kg/ha), and RDF with micronutrient alone. The treatment combining 45 kg/ha of sulfur with RDF and micronutrients showed superior results, having larger plants (50.32 cm), yielding an average of 42.34 pods per plant with seed weight of 40.17 g per plant. Haulm yield reached 3360 kg/ha, while seed yield was noted 2499.47 kg/ha. Additionally, the oil and protein contents were enhanced, recorded at 19.2% and 41.23% respectively. This treatment underscores the potential for integrated nutrient management to improve soybean yield and quality.

Keywords Foliar nutrition, Micronutrient, Protein content, Seed yield, Soybean.

INTRODUCTION

Soybean (*Glycine max* L.), often referred to as the "Golden Bean" or the "Miracle Crop" of the 21st century, is celebrated for its remarkable nutritional and economic potential (Sahebagouda *et al.* 2019). As a vital leguminous crop, it is renowned for its high protein content (40–42%) and oil concentration (18–20%), making it an essential commodity for the global food and industrial sectors (Shea *et al.* 2020). India is a major contributor to global soybean production, accounting for 18% of the world's total output, with key production states including Maharashtra, Madhya Pradesh, Karnataka, Rajasthan, and Telangana (Dil-

Heena A. Magodia[1], Pooja V. Jagasia[2*], Archana P. Kale[3]

[2]Professor

[1,2]Vivekananda Education Society's, College of Arts, Science & Commerce, University of Mumbai, Sindhi Society, Chembur, Mumbai 400071, Maharashtra, India

[3]Research Scientist and Chief Manager, Rastriya Chemical and Fertilizer Company, Mumbai, India

Email: pooja.jagasia@ves.ac.in
*Corresponding author

awari *et al.* 2022). Currently, soybean is cultivated over approximately 12.27 million hectares in India, with a production of 12.99 million tonnes and an average productivity of 1059 kg/ha. Maharashtra alone contributes significantly with 4.69 million hectares under cultivation and a slightly higher productivity of 1168 kg/ha (Rani 2023).

In recent years, soybean has arisen as a vital oilseed crop in India, ranking third in area and production after groundnut and rapeseed-mustard. Among the innovations to enhance its growth and yield, foliar nutrient application has gained prominence as an efficient method, especially under rainfed and reduced tillage conditions. The foliar application delivers nutrients directly to plant leaves, bypassing limitations such as poor soil fertility or inadequate irrigation. This method has been found more effective than traditional soil applications, particularly in challenging agro-climatic conditions (Sharma and Singh 2024).

Sulfur, an essential secondary nutrient, plays a pivotal role in enhancing soybean growth and productivity. Often referred to as the "Master Nutrient" for oilseeds and pulses, it is fundamental to protein, oil, and vitamin synthesis as it constitutes amino acids like cysteine, methionine, and cystine (Rathor *et al.* 2017). Sulfur deficiencies are increasingly prevalent due to intensive agricultural practices, reliance on high-analysis fertilizers lacking sulfur, and reduced application of organic amendments such as farmyard manure. These deficiencies not only impair protein quality and nitrogen-use efficiency (Movalia and Savalia 2020, Singh *et al.* 2017) but also limit overall yield potential.

Addressing this challenge requires a comprehensive sulfur management strategy, incorporating optimal quantities, application timing, and effective methods tailored to crop physiology and soil conditions (Abido 2018, Sridevi *et al.* 2024). Sulfur has also shown utility as a soil amendment for reducing pH, and improving the availability of micronutrients like boron, copper, iron, and zinc, which tend to decline in alkaline soils (Grace and Dawson 2024). The combined application of elemental sulfur to soil and micronutrient foliar sprays offers a promising integrated approach to mitigating nutrient deficiencies, enhancing growth, and maximizing soybean productivity in diverse agroecosystems (Lakshman *et al*. 2015, Gill and Sharma 2017).

This study explores the synergistic effects of elemental sulfur in soil and foliar micronutrient application on the growth and productivity of soybean. It aims to contribute to sustainable agricultural practices by addressing critical nutrient deficiencies and optimizing resource use for enhanced crop performance.

MATERIALS AND METHODS

An experiment was conducted at the premises of "Rashtriya Chemicals and Fertilizers Limited, Mumbai, Maharashtra", during the "*rabi* season" of December 2021, to evaluate the effects of elemental sulfur and micronutrient foliar application on the growth and productivity of soybean (*Glycine max* L.). The research was conducted to evaluate the effects of applying different levels of elemental sulfur—15, 30 and 45 kg/ha—in conjunction with a full complement of recommended doses of fertilizers (RDF), having 50 kg/ha (N), 75 kg/ha (P), and 45 kg/ha (K) respectively. This fertilization regimen was further enriched with targeted foliar sprays of essential micronutrients to ensure comprehensive nutrient support and address potential deficiencies. The micronutrient spray formulations included copper at 1.0%, zinc at 3.0%, manganese at 1.0%, iron at 2.5%, boron at 0.5%, and molybdenum at 0.1%. The experiment was carried out on red, slightly alkaline soil. Soil physico-chemical properties and plant parameters were analysed before sowing (December) and post-harvest (March) following Food and Agriculture Organization (FAO) protocols (FAO 2022).

The trial was designed as RBD with 6 treatments each replicated 5 times (Table 1). Each treatment plot spanned an area of 4.5 m² comprised of 7 rows. Each row contained 28 plants, with 10 plants per treatment tagged for parameter evaluation. A basal application of 50 kg/ha N, 75 kg/ha P, and 45 kg/ha K was provided using Suphala (N15:P15:K15), urea, and Muriate of potash. Elemental sulfur and compost were also incorporated as a soil amendment. Foliar applications of micronutrient mixtures were administered twice,

Table 1. Impact of elemental sulfur and micronutrient spray on growth parameters and yield of soybean.

Treatments	Height of plant (cm)	Weight of pod/plant (gram)	Stover yield kg/ha	Seed yield kg/ha	100 seed weight	Oil %	Protein content (%)
100% RDF (T1)	42.975	33.244	2488.889	1811.91	10.83	17.90	36.96
RDF+15 S+Mn (T2)	45.93	36.20	2712.89	1968.06	11.27	18.58	38.89
RDF+30 S+Mn (T3)	48.378	40.74	3011.556	2218.84	11.87	18.92	40.01
RDF+45 S+Mn (T4)	**50.32**	**42.34**	**3360.14**	**2499.47**	**12.28**	**19.22**	**41.23**
100% RDF + 45 S (T5)	46.18	38.32	2899.56	2123.15	11.28	18.74	39.02
100% RDF + Mn (T6)	44.99	35.78	2663.11	2020.84	11.03	18.45	38.41
Standard error							
Mean	0.4441	0.50	63.46	45.49	0.07	0.29	1.06
CD (0.05)	1.3102	1.47	187.21	134.18	0.20	NS	NS
CV %	2.1375	2.96	4.97	4.83	1.34	3.49	5.05

at 45 and 60 days after sowing, during the flowering stage. Oil content in seeds was measured using Soxhlet extraction with petroleum ether (boiling point 60°C) Putra *et al.* (2018), while protein content was determined using Lowry's method with a spectrophotometer Lowry *et al.* (1951).

To assess yield attributes, random samples of 10 plants per treatment were collected at 110 DAS (harvest stage). The study assessed several agronomic and quality parameters, including plant height, 100-seed weight, pod weight per plant, haulm yield (kg/ha), oil content, protein content, and seed yield (kg/ha). Plant height, measured in centimeters, was determined at the maturity stage by using a measuring tape to record the distance from the base of the main stem to the tip of the newest leaf. To evaluate pod production, the total number of pods on each marked plant was counted, and the average number of pods per plant was calculated based on these observations. Statistical analysis was performed using SPSS version 26.

Preparation of mixture of micronutrients

Following the guidelines from the Maharashtra Gazette, a multimicronutrient fertilizer spray was prepared. The chemicals used were $CuSO_4.7H_2O$ (4.49 g), $ZnSO_4.7H_2O$ (15.4 g), $MnSO_4$ (2.71 g), $FeSO_4.7H_2O$ (17.28 g), Boric Acid (2.86 g), and Ammonium molybdate (0.72 g), which were dissolved in demineralized water at 65°C-70°C for two hours. The volume was then made up to 100 ml, and the solution was filtered. This stock solution was diluted to 1ml in 1000 ml of distilled water and used as a foliar spray on the crop.

RESULTS AND DISCUSSION

The optimal level of sulfur in soil and timing for micronutrient foliar spray applications significantly influence growth parameters and yield of crops (Dheri *et al.* 2021). The present study evaluated the impact of various sulfur (S) levels and micronutrient spray (MS) combinations on the growth attributes, seed and haulm yield, and quality of oil of soybean. We noted a significant improvement in all parameters within the RDF + 45S + MS (T4) combination crops, delivering the most pronounced effects compared to the control (100% RDF, T1). The spray of micronutrients twice during the vegetative stage helped crops to perform better compared to control plants.

The study found that varying sulfur levels did not significantly impact the protein and oil content of grains. However, a sulfur concentration of 45 kg/ha led to the highest protein and oil levels, while the control exhibited the lowest. This suggests that sulfur influences these contents, as it is essential for synthesizing fatty acids and sulfur-containing amino acids crucial for proteins. These results confirm the symbiotic role of sulfur and micronutrients and are in line with the finding of (Chaudhary *et al.* 2014),

Several research on the role of sulfur indicated that applying sulfur at rates between 30 kg/ha to 45 kg/ha can lead to notable increases in soybean physical parameters, productivity, and oil content. Mibang *et al.* (2024) study demonstrated that 45 kg

S/ha (using gypsum) significantly improved plant height, leaf length, and overall biomass. In contrast, Thenua *et al.* (2014) study found that applying 40 kg S/ha resulted in the highest soybean yield. Foliar applications of 0.5% chelated zinc and boron at the pod initiation stage significantly increased pod numbers and seed yield, outperforming treatments without foliar nutrition (Dass *et al.* 2022). Using biostimulants and specific nutrient combinations during the vegetative and reproductive stages also yielded positive results, enhancing overall growth and yield (Silva *et al.* 2017). Hence, the timing and type of nutrient application are crucial; it is also essential to consider environmental factors and soil conditions that may affect nutrient uptake and crop response.

Although these studies confirm micronutrient spray and S can improve soybean growth and yield, the present study is the first report to find a combination of elemental sulfur (45 kg/ha) along with Micronutrient spray is very effective. We identified the effect of this combination on various parameters such as height, weight, number of seeds, pod, haulm, oil, and protein content.

According to Gill and Sharma (2017) Soybeans are rich in micronutrients, and their levels can be increased through biofortification and fertilizers to combat nutrient deficiencies. Micronutrients play a crucial role in the quality and quantity of soybean yields. Research indicates that sulfur supplementation notably enhances zinc and iron levels in mature soybean seeds, while its effect on copper and manganese is minimal.

Plant height: The plant height of soybean (Table 1) increased consistently across treatments, with T4 (50.32 cm) showing the highest increase, 17.09% higher than T1 (42.98 cm). Lower levels of sulfur with micronutrients also enhanced height (T2: 45.93 cm, T3: 48.38 cm), albeit to a lesser extent. Sole sulfur or micronutrient applications (T5 and T6) resulted in modest improvements (46.18 cm and 44.99 cm, respectively). Bhutia and Misal (2024) have reported similar findings due to the application of sulfur.

Pod weight per plant: Pod weight (Table 1) followed a similar trend, increasing from 33.24 g in T1 to 42.34 g in T4 (27.36% higher). Intermediate treatments (T2: 36.20 g, T3: 40.74 g) also improved pod weight compared to T1 (Table 1). Sole applications, T5 and T6, led to smaller gains (38.32 g and 35.78 g). Magodia *et al.* (2024) have also documented observations supporting these results only by adding sulfur.

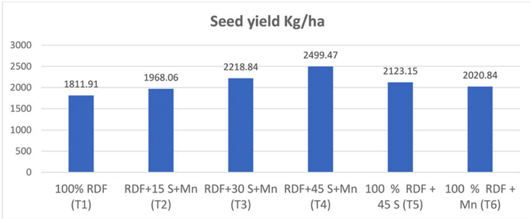

Fig. 1. Role of elemental sulfur and micronutrient spray on seed yield kg/ha of soybean.

Stover yield: Maximum stover yield was recorded in T4 (3360.14 kg/ha), a 35.01% improvement over T1 (2488.89 kg/ha) observed in (Table 1). Intermediate levels of sulfur and micronutrients (T2 and T3) yielded 2712.89 kg/ha and 3011.56 kg/ha, respectively, while T5 and T6 yielded 2899.56 kg/ha and 2663.11 kg/ha (Table 1). Similar study on soybean by Lakshman *et al.* (2015) noted sulfur plays a crucial role in promoting vegetative growth, and its deficiency during this stage can lead to a significant lessening in biomass and the number of branches per plant.

Seed yield: Seed yield saw in (Fig.1) the highest increase of 37.95% in T4 (2499.47 kg/ha) compared to T1 (1811.91 kg/ha). Treatments T2 (1968.06 kg/ha) and T3 (2218.84 kg/ha) produced better yields than sole applications in T5 (2123.15 kg/ha) and T6 (2020.84 kg/ha). Devi *et al.* (2012) as well as MacMillan and Gulden (2020) further corroborated these trends in soybean, highlighting the critical importance of sulfur for optimal seed yield.

100-seed weight: The 100-seed weight increased most in T4 (12.28 g), reflecting a 13.37% improvement over T1 (10.83 g). The incremental improvement in other treatments were T2 (11.27 g), T3 (11.87 g), T5 (11.28 g), and T6 (11.03 g). The importance of sulfur and foliar spray in improving seed was also reported by Magodia *et al.* (2024a) and Sharma and Singh (2024) respectively.

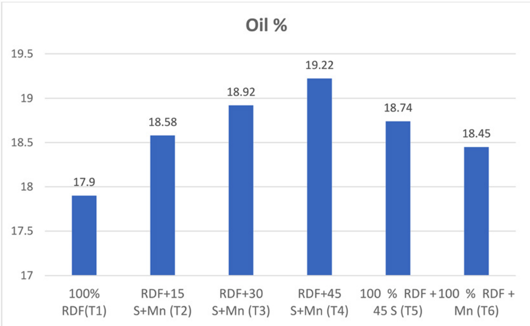

Fig. 2. Role of elemental sulfur and micronutrient spray on oil content of soybean.

Oil content: Fig. 2 indicates the total percentage of oil content improved across all treatments, peaking at 19.22% in T4 (7.40% higher than T1). T2, T3, T5, and T6 had incremental improvements of 18.58%, 18.92%, 18.74%, and 18.45%, respectively. Magodia *et al.* (2024a) reported that increased sulfur application significantly enhances oil content in soybean seeds, underlining its multifaceted role in improving crop quality.

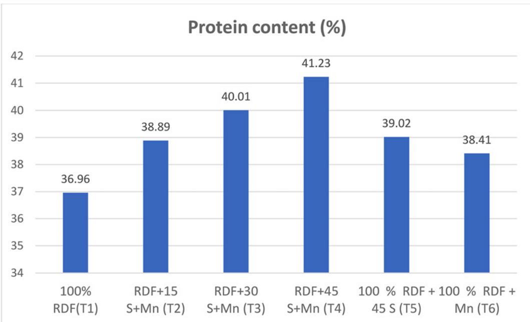

Fig. 3. Role of elemental sulfur and micronutrient spray on protein content of soybean.

Protein content: Protein content increased by 11.55% in T4 (41.23%) compared to T1 (36.96%). T3 (40.01%) and T2 (38.89%) showed moderate enhancements, while T5 (39.02%) and T6 (38.41%) demonstrated the smallest gains (Fig. 3). Krishnan and Jez (2018) have documented the improved protein content in soybean due to sulfur, however Lyngdoh *et al* (2019) noted it due to micronutrient spray.

CONCLUSION

T4 (RDF + 45S + Mn) consistently outperformed all other treatments, indicating that a higher sulfur dose combined with micronutrient application effectively enhances soybean growth, yield, and quality. Intermediate sulfur levels with micronutrients (T2 and T3) also demonstrated significant benefits, while sole applications (T5 and T6) provided modest improvements.

REFERENCES

Abido WAE (2018) Impact of phosphorus and sulph ur fertilizer levels on soybean productivity. *Journal of Plant Production Mansoura Univ* 9(12):1223–1230.

Bhutia DR, Misal NB (2024) Influence of different rates of nitrogen and sulphur on growth, yield and yield attributes of cabbage (*brassica oleraceae* L.). *Environment and Ecology* 42(2B) : 855-859.

Chaudhary P, Jhajharia A, Kumar R (2014) Influenced of sulfur and zinc fertilization on yield, yield components and quality traits of soybean (*Glycine max* L.). *The Bioscan* 9(1): 137-142.

Dass A, Rajanna GA, Babu S, Lal SK, Choudhary AK, Singh R *et al.* (2022) Foliar application of macro- and micronutrients improves the productivity, economic returns, and resource-use efficiency of soybean in a semiarid climate. *Sustainability* 14(10): 5825.

da Silva NF, Clemente GS, Teixeira MB, Soares FA, Cunha FN, da Silva Azevedo LO (2017) Use of foliar fertilizers for the specific physiological management of different soybean crop stages. *American Journal of Plant Sciences* 8(4): 810.

Devi NK, Singh LNK, Singh MS, Singh SB, Singh KK (2012) Influence of sulfur and boron fertilization on yield, quality, nutrient uptake and economics of soybean (*Glycine max*) under upland conditions. *Journal of Agricultural Science* 4(4): 1–10.

Dheri GS, Saini SP, Brar BS, Sandhu OS (2021) Response of soybean (*Glycine max*) to different sources and levels of sulfur application. *The Indian Journal of Agricultural Sciences* 91(8):1242–1246.

Dilawari R, Kaur N, Priyadarshi N, Prakash I, Patra A, Mehta S, Singh B, Jain P, Islam MA (2022) Soybean: A key player for global food security. In: Soybean improvement: Physiological, molecular and genetic perspectives. Cham: Springer International Publishing, pp 1-46.

FAO (2022) Food and Agriculture Organization, Fertilizer and Plant Nutr Bull. *Chapter 3 Soil Analysis* 19: 44-75.

Gill GK, Sharma S (2017) Effect of sulfur supplementation on micronutrients, fatty acids and sulfur use efficiency of soybean seeds. *International Journal of Environment, Agriculture and Biotechnology* 2(4): In press.

Grace PS, Dawson J (2024) Influence of nitrogen and iron on yield and economics of foxtail illet (*Setaria italica* L.). *Environment and Ecology* 42(1) : 159-162.

Krishnan HB, Jez JM (2018) The promise and limits for enhancing sulphur-containing amino acid content of soybean seed.

Plant Science 272: 14-21.

Lakshman K, Vyas AK, Shivakumar BG, Rana DS (2015) Effect of levels and time of sulphur application on growth, yield and quality of soybean (*Glycine max*). *Indian Journal of Agronomy* 60: 121–125.

Lowry DH, Roseborrough NT, Fam AL, Ronald RJ (1951) Protein measurement with the folin phenol reagent. *J Biol Chem* 193: 265-275.

Lyngdoh B, Krishnamurthy N, Jayadeva HM, Gowda J, Seenappa C (2019) Influence of foliar nutrition on the performance of soybean (*Glycine max* (L.) Merrill). *Mysore Journal of Agricultural Sciences* 53: 57-61.

MacMillan KP, Gulden RH (2020) Effect of seeding date, environment and cultivar on soybean seed yield, yield components, and seed quality in the Northern Great Plains. *Agronomy Journal* 112(3) : 1666-1678.

Magodia HA, Jagasia PV, Kale AP (2024) Synergistic Effects of ES and recommended fertilizer doses on onion (*Allium cepa* L.) yield, nutrient uptake and retention. *Annals of Plant and Soil Research* 26(4): 692-699.

Magodia HA, Jagasia PV, Kale AP (2024a) Growth attributes of Maize (*Zea Mays* L.) Crop and nutrient uptake as impacted by sulfur and micronutrients application. *International Research Journal on Advanced Engineering Hub (IRJAEH)* 2(04): 907-919.

Mibang A, Doruk K, Lipi R, Sanchung L (2024) Studies on synergistic interaction of different sources and levels of sulfur on growth of black soybean. *International Journal of Research in Agronomy* 7(7): 91–97.

Movalia J, Savalia SG (2020) Effect of sources and levels of sulfur on growth and yield of *kharif* soybean (*Glycine max* (L.) Merrill). *International Journal of Current Microbiology and Applied Sciences* 9: 440–451.

Putra NR, Yunus MAC, Ruslan MSH, Idham Z, Idrus FN (2018) Comparison extraction of peanut skin between CO_2 supercritical fluid extraction and soxhlet extraction in terms of oil yield and catechin. *Pertanika Journal of Science and Technology* 26 (2): 799-810.

Rani M (2023) Growth and trends of agriculture: Food grain production and area in India. *Economic and Regional Studies/ Studia Ekonomiczne i Regionalne* 16(2): 275-285.

Rathor G, Chopra N, Bhargava BH, Sohani R, Chore G, Patel R (2017) Influence of sulfur application on oil content and productivity of soybean (*Glycine max* (L.) Merr.) in Malwa Nimar of Madhya Pradesh. *Journal of Oilseeds Research* 34(3): 175.

Sahebagouda T, Chikkaramappa, Basavaraja PK (2019) Effect of varied levels of sulfur and sources of organics on growth, yield parameters and economics of soybean (*Glycine ma*x L.) in Alfisols of Karnataka. *Indian Journal of Pure & Applied Biosciences* 7(1):14–148.

Sharma SK, Singh K (2024) Impact of foliar application of nutrients on yield and economics of Cluster Bean (*Cyamopsis tetragonoloba* L.) under dryland condition. *Environment and Ecology* 42(2): 492-497.

Shea Z, Singer WM, Zhang B (2020) Soybean production, versatility, and improvement. Legume Crops—Prospects, Produc tion and Uses, pp 29-50.

Singh S, Singh V, Layek S (2017) Influence of sulfur and zinc levels on growth, yield and quality of soybean (*Glycine - max* L.). *International Journal of Plant & Soil Science* 18(2) : 1-7.

Sridevi G, Santhoshkumar P, Thiyageshwari S (2024) Long term effect of integrated nutrient management on soil organic carbon status and yield of sunflower in alfisols. *Environment and Ecology* 42(1): 181-184.

Thenua OVS, Singh K, Raj V, Singh J (2014) Effect of sulfur and zinc application on growth and productivity of soybean (*Glycine max* (L.) Merr.) in northern plain zone of India. *Annals of Agricultural Research* 35(2) : In press.