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Synergistic Effects of ES and recommended fertilizer doses on onion (*Allium cepa* L.) yield, nutrient uptake and retention

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ABSTRACT

This study investigates the synergistic effects of ES and recommended fertilizer doses (RDF) on the growth, yield, nutrient content, and nutrient uptake of onion crops (*Allium cepa* L.) in Maharashtra, India. Conducted as a Randomized Block Design with six treatments, the research evaluated control (T_1), RDF with no sulphur (T_2), and RDF combined with increasing doses of elemental sulphur (ES): 20, 40, 60, and 80 kgha^{-1}called T_3, T_4, T_5 and T_6 respectively. The results indicate that the application of 60 kg/ha of ES (T_5) significantly enhanced key growth parameters, including leaf height, bulb diameter, and overall yield, with the highest recorded yield of 2938.21 kgha^{-1} when compared to control (p=<0.05). Nutrient analysis revealed that sulphur application significantly improved the concentrations of both macro- and micronutrients (N, P, K, S, Cu, Zn, Mn, Fe) in onion bulbs and leaves compared to control (p=<0.05). 60 kgha^{-1} ES combined with 100% RDF demonstrated optimal plant growth, yield, nutrient uptake, and retention. However, further increases in sulphur dosage (T6) resulted in diminished returns, suggesting potential nutrient saturation or antagonistic effects. The findings underscore the importance of optimizing sulphur application to maximize onion yield and nutrient efficiency.

Keywords: Chlorophyll, ES, macronutrients, micronutrients, onion growth

INTRODUCTION

Onion, a staple vegetable in the Mediterranean diet, has gained global recognition for its pivotal role as a culinary ingredient. India is the second-largest producer of onions globally, contributing approximately 20 million tons annually from around 1.17 million hectares, which emphasizes its significant role in the global onion production and export market (Nivetha and Uma, 2020). Onion cultivation in India spans 1.54 million hectares, with an estimated production of 25.44 million metric tons (National Horticulture Board, 2023-24). India ranks as the second-largest onion-growing country globally, following China. The leading onion-producing states in India are Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Rajasthan, and Telangana (Kaur *et al.,* 2017). In the 2023-24 growing season, Maharashtra was the top producer, contributing 35% of the national output, followed by Madhya Pradesh at 17% (APEDA, 2023-2024). However, onion production in India is projected to decrease by 15% compared to the previous year (National Horticulture Board, 2023-24).

Onions require high sulphur (S) concentrations for optimal growth and yield. Though classified as a secondary nutrient, sulphur is now recognized as the fourth essential macronutrient, following nitrogen (N), phosphorus (P), and potassium (K) (Tandon *et al.,* 2002, Singh *et al.,* (2015). These key plant nutrients (N, P, K, S) significantly affect onion growth, development, and yield. Several micronutrients such as Copper (Cu), Zinc (Zn), Manganese (Mn), and Iron (Fe) also play a critical role in plant metabolic processes, enzyme activity, and nitrogen fixation, all of which are essential for improved crop growth parameters (Ballabh *et al.,* 2012). Nutrient imbalance is one of the major reasons for low nutrient uptake in plants, leading to low plant growth and yield. The sulphur deficiency in soils has been increasingly recognized in India due to the adoption of crop varieties that require more sulphur to grow, and excessive use of fertilizers

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lacking sulphur (Shukla *et al.,* 2016). Sulphur deficiency is a significant issue in Indian agriculture, with an average deficiency of 32.9% in Indian soils and 27.48% in Maharashtra (Katkar *et al.,* 2017). However, the addition of sulphur is known to improve nutrient availability in soils, particularly alkaline and calcareous soils (Soaud, 2011); the impact of the combination of ES with NPK fertilizers has not been assessed in the typical onion field of Maharashtra, India. So, the present study aimed to evaluate the impact of ES doses on the quality, yield, and macro and micronutrient uptake in onions.

MATERIALS AND METHODS

Experiment Design and Setting

An experiment was conducted during the 2023 and 2024 Rabi season in the Nandur Shingote village, Nashik district, Maharashtra, India, to assess the effects of different sulphur doses on the yield and quality parameters of onion crops. The experiment was arranged in a Randomized Block Design (RBD) with five replications, each covering an area of approximately 3.68 square meters. Each plot contained 40 plants. The experiment included six treatments: a control T_1 (no sulphur or RDF application) and five treatments (T_2-T_6) having RDF with increasing doses of elemental sulphur (ES) (0, 20, 40, 60, and 80 kg/ha respectively). ES (by-product of Bharat Petroleum Corporation Limited) was applied at the time of transplanting.

Transplantation of seedlings

Seven-week-old onion seedlings were transplanted with a spacing of 15 cm × 10 cm. Suphala fertilizer (N_{15}:P_{15}:K_{15}), Rashtriya Chemical Fertiliser Limited, Mumbai, India, was used during transplantation. To obtain the recommended doses of potassium (40 kg/ha each), nitrogen (120 kg/ha), phosphorus (60 kg/ha), additional urea and diammonium phosphate were added, 30 days after transplanting. Regular irrigation (watering twice a week), weeding, and plant protection measures were implemented as needed. The crop was harvested 120 days after transplanting (Rao *et al.,* 2020).

Study of physical parameters

Plant morphological characteristics were observed and recorded from ten randomly selected competitive plants for each treatment and replication. Field data were collected on plant height, bulb equatorial and polar diameter, neck diameter, average bulb weight, and chlorophyll content. Bulb yield (kg/ha) was calculated using the yield from each plot. After 120 days, the entire plot was harvested, and soil and plant samples were collected for further analysis.

Study of nutrient uptake

The collected plant samples were divided into bulbs and leaves. Specimens were dried in the sun for 8 to 10 days and thereafter pulverised. Nutrients, including N, P, K, S, Cu, Zn, Mn and Fe were extracted using wet acid digestion, and their levels were determined using an Inductively Coupled Plasma Spectrophotometer (ICP-OES) (Miller *et al.,* 2013). Nutrient uptake in onion crops was calculated by multiplying the nutrient concentration (%) with dry matter yield from each plot.

Statistical Method

The data obtained were statistically analyzed following the procedures outlined by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Growth and yield parameters

ES significantly impacts growth parameters across various crops, enhancing nutrient availability and overall plant health. In sorghum, ES application significantly increased fresh and dry weights, as well as nutrient content, demonstrating its critical role in plant development (Ariraman *et al.,* 2020). We noted that growth parameters most significantly increased to 60 kg/ha of ES. The maximum plant height (70.02 cm) was recorded with 60 kgha^{-1} of ES combined with 100% RDF (T_5), which was 36.5% more than the control plant height (51.27 cm). The same dose also resulted in the highest dry weight of onion bulbs (27.03 g), maximum fresh bulb weight (178.83 g), and highest polar diameter (7.03 cm). However, neck diameter was not affected by adding ES.

Table 1: Impact of ES on growth parameters

Treatment	Height of leaves (cm)	Equatorial Diameter (cm)	Polar Diameter (cm)	Neck diameter (cm)	Chlorophyll content (mg/100gm)	Fresh weight of bulb (gm)	Dry weight of bulb (gm)	Bulb yield (kg/ha)
T_1	51.03	4.21	4.35	0.55	0.46	82.15	14.57	1606.05
T_2	59.76	4.86	5.05	0.65	0.50	127.24	19.48	2146.16
T_3	60.80	5.56	5.91	0.70	0.54	153.20	20.73	2504.39
T_4	63.97	6.56	6.52	0.76	0.60	162.23	24.29	2675.64
T_5	70.02	6.79	7.03	0.82	0.64	178.83	27.03	2938.21
T_6	64.54	6.64	6.85	0.78	0.61	172.55	25.36	2713.07
SEM±	1.18	0.08	0.06	0.06	0.01	2.14	0.61	113.70
CD (.05)	4.37	0.24	0.19	NS	0.04	6.31	1.81	335.41
CV %	5.37	3.19	2.38	19.83	5.77	3.28	6.27	10.46

T_1 Control, T_2: 100% RDF, T_3: 100 % RDF + 20 kg elemental S, T_4: 100 % RDF + 40 kg elemental S, T_5: 100 % RDF + 60 kg elemental S, T_6: 100 % RDF + 80 kg elemental S

Sulphur is essential for synthesizing coenzyme A and amino acids, which are necessary for protein synthesis and the formation of disulfide bonds, crucial for maintaining structural integrity in plant protoplasm. Higher levels of sulphur resulted in notable improvements in plant height and root length in wheat, improved yield in groundnut and significantly increased fresh and dry weights in rice (Nadeem *et al.,* 2023; Muhammad *et al.,* 2024; Ram *et al.,* 2014). Previously, Tripathy *et al.* (2013) noted similar results by using Gypsum as a source of sulphur for onion. Previous studies by Rizk *et al.* (2012) also noted overall improvements in growth and yield of the onion by using sulphur, nitrogen and boron-rich fertilizers.

A significant decline in plant height was observed at the highest sulphur application rate (80 kg/ha), suggesting that while adequate sulphur levels benefit plant growth, excessive doses can adversely affect crop growth and development. We also noted higher sulphur dosage (80 kg/ha) resulted in a decline in other growth parameters, with no significant additional benefits (Figure 1). Excessive sulphur application was noted to adversely affect the growth and development of onions, might be due to a potential nutritional imbalance, resulting in reduced bulb size. as observed by Mishu *et al.* (2013), D'Souza *et al.* (2015), Tripathy *et al.* (2013), and Meher *et al.* (2015).

Impact of ES on Chlorophyll Content

Sulphur plays a crucial role in the composition of various enzymes and amino acids necessary for chlorophyll synthesis (Chandra and Pandey *et al.* 2014). We also recorded highest chlorophyll content was in the T_5 treatment (0.64 mg/100 g), which was comparable to T_4 (40 kg/ha) (0.60 mg/100 g) and T_6 (80 kg/ha) (0.61 mg/100 g). The lowest chlorophyll content was observed in the control treatment (0.46 mg/100 g) (Table 1). Similar findings have been documented by Chandra and Pandey *et al.* (2014) and Verma *et al.* (2013). The increased chlorophyll content in the present study might be seen due to sulphur-induced activation of chemical and biological processes involving chlorophyll synthesis and the promotion of photosynthesis (Channagoudar and Janawade, 2006).

Impact of ES on yield

The yield parameters, the most critical determinant for the acceptance of agricultural practices, were significantly impacted by varying sulphur levels in this study. The average yield of onion bulbs showed a significant increase as the level of sulphur application increased up to 60 kg/ha, resulting in a yield of 2938.21 kg/ha (Table 1). However, a higher dose of sulphur (80 kg/ha) led to a decrease in onion yield. These findings suggest that sulphur deficiency negatively impacts onion growth and yield. However, enhanced fertilizer treatments, particularly with sulphur, resulted in higher yields of onion bulbs due to increased nutrient absorption from the soil. This data is further supported by studies conducted by Pradhan *et al.* (2015), Ukey *et al.* (2015), Gurjar *et al.* (2019), and Singh *et al.* (2020). A decrease in yield was observed with higher sulphur application rates (above 60 kg/ha). It clearly demonstrates the potential phytotoxicity or negative impact of excessive sulphur application. It is possibly due to nutrient imbalances and other limiting factors in the soil that cannot be compensated for sulphur alone (Ukey *et al.* (2015).

Table 2: Percent Macronutrient contents in bulbs and leaves

Treatment	Bulbs				Leaves			
	N %	P%	K %	S%	N %	P%	K %	S%
T_1	0.82	0.51	1.50	0.29	1.14	0.167	1.28	0.20
T_2	1.08	0.60	1.65	0.33	1.23	0.207	1.54	0.24
T_3	1.42	0.73	1.77	0.34	1.36	0.231	1.82	0.27
T_4	1.83	0.82	1.80	0.39	1.54	0.263	2.14	0.27
T_5	1.93	0.90	1.91	0.41	1.65	0.304	2.39	0.30
T_6	1.91	0.85	1.85	0.44	1.58	0.276	2.19	0.29
SEM ±	0.04	0.02	0.12	0.01	0.13	0.01	0.05	0.02
CD (0.05)	0.12	0.06	NS	0.04	NS	0.03	0.14	NS
CV (%)	6.28	6.28	15.74	7.36	19.87	10.21	5.51	18.18

Macronutrient contents in bulbs and leaves of onion

Table 2 indicated that Macronutrient content, including N, P, K, S, showed significant variation across the six treatments. A clear upward trend of nutrient concentrations in onion bulbs and leaves was noted as the concentration of ES was increased. However, statistically significant dose-dependent increases in N and P concentrations in bulbs and phosphorus in leaves were noted (Table 2). Our findings align with Chandel *et al.* (2012), who reported increased phosphorus uptake in the presence of sulphur in garlic. However, Chattoo *et al.* (2019) observed increased NPK levels as an effect of 45kg/ha gypsum as a source of sulphur. Among all nutrients, only sulphur content increased gradually from 0.29% to 0.44% in bulbs at 80 kg/ha, which might be because sulphur is a necessary component of enzymes involved in nitrogen metabolism, and its application can enhance nitrogen absorption from soil and its assimilation (Ukey *et al.,* 2015). However, a statistically insignificant increase in sulphur accumulation (0.20%-0.30%) was noted across the treatments in leaf tissues. Our results were similar to Pradhan *et al.* (2015) in onion and Singh (2017) in pearl millet study.

Table 3: Micronutrient contents in bulbs and leaves

Treatment	Bulbs				Leaves			
	Cu ppm	Zn ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	Mn ppm	Fe ppm
T1	15.26	40.71	16.62	87.738	26.95	19.51	41.60	411.902
T2	19.45	50.85	19.46	104.97	35.39	22.64	53.56	466.834
T3	20.91	58.58	20.67	127.1	40.67	26.82	56.09	514.554
T4	21.86	64.52	22.93	180.1	44.98	32.13	58.66	594.726
T5	23.71	79.26	24.67	187.98	52.08	37.10	65.25	615.894
T6	22.49	75.18	23.88	179.32	48.72	39.83	59.86	576.756
SEM ±	1.82	3.43	1.90	4.67	1.64	1.44	4.87	12.54
CD (0.05)	NS	10.13	NS	14.06	4.85	4.25	NS	36.72
CV (%)	19.74	12.48	19.93	17.37	8.87	10.85	19.51	5.25

Micronutrient contents of onion bulb and leaves

Table 3 shows that content of micronutrient Cu, Zn, Mn, and Fe, exhibited a consistent dose-dependent increase across the treatments, reflecting enhanced micronutrient accumulation and availability in bulbs and leaves. However, an increase in copper and manganese content was found to be non-significant in the onion bulb. Several research indicate that the application of micronutrients such as boron, copper, and zinc enhance their accumulation in both the leaves and bulbs of onions parameters (Zahed *et al.,* 2021). Copper content increased from 15.26 ppm and 26.95 ppm in control to a maximum of 23.71 ppm and 52.08 ppm on T5 treatment in bulbs and leaves, respectively (Table 3), While the content of copper in leaves exhibited at par with (T6) 48.72 ppm. Zinc content increased from 40.71 ppm and 19.51 ppm in control to a maximum of 79.26 ppm and 37.10 ppm on T5 treatment in bulbs and leaves, respectively, which was found to be at par with T6 (75.18 ppm) in onion bulbs. Similarly, Badapmain *et al.,* (2023) noted enhancing yield, nutrient uptake and iron nutrition in soybean. A statistically significant increase in Fe concentrations of bulbs and leaves suggests that 60 kg/ha of ES optimally enhanced the iron micronutrient contents. On comparing the onion bulb and leaves, copper, manganese, and iron were more than double in leaves and zinc content was higher in bulbs. However, Bertino *et al.* (2022) have reported that higher concentrations of micronutrients do not significantly affect the number of leaves or overall yield in onions.

Table 4: Macronutrient Uptake from onion bulb and leaves

Treatment	Bulb ($kgha^{-1}$)				Leaves ($kgha^{-1}$)			
	N $kgha^{-1}$	P $kgha^{-1}$	K $kgha^{-1}$	S $kgha^{-1}$	N $kgha^{-1}$	P $kgha^{-1}$	K $kgha^{-1}$	S $kgha^{-1}$
T_1	13.31	8.25	24.10	4.62	3.76	0.55	4.22	0.67
T_2	23.28	12.89	35.56	7.10	5.51	0.94	6.98	1.08
T_3	32.83	16.70	40.79	7.83	6.17	1.05	8.26	1.21
T_4	49.03	21.86	48.01	10.31	8.12	1.35	11.00	1.42
T_5	56.58	26.55	55.95	11.98	8.99	1.66	13.03	1.67
T_6	51.85	22.95	50.24	11.99	8.81	1.54	12.02	1.58
SEM ±	1.55	0.61	3.15	0.33	0.62	0.05	0.17	0.09
CD (0.05)	4.56	1.81	9.30	0.97	1.84	0.14	0.50	0.28
CV (%)	9.14	7.55	16.61	8.22	20.22	9.26	4.14	16.42

Macronutrient uptake by onion bulb and leaves

T5 exhibits the highest nutrient uptake, with nitrogen, phosphorus, potassium, and sulphur uptake at 56.58 kg/ha, 26.55 kg/ha, 55.95 kg/ha, and 11.98 kg/ha, respectively in bulbs and 8.99kg/ha, 1.66kg/ha, 13.03kg/ha and 1.67kg/ha in onion leaves respectively (Table 4). Similarly, NPK and S uptake was maximum in leaves at T_5 treatment, confirming 60 kg/ha is the optimal level of sulphur required. However, uptake was much higher by bulbs compared to leaves. Various studies have reported similar findings regarding the use of sulphur fertilizers to enhance crop nutrient uptake, including research by Pradhan *et al.* (2015), Rathod *et al.* (2020) on onions, Sisodiya *et al.* (2017) on groundnut, and Klikocka *et al.* (2019) on spring rye grain.

Table 5: Micronutrient uptake by bulbs and leaves

Treatment	Bulbs				Leaves			
	Cu gm/ha	Zn gm/ha	Mn gm/ha	Fe gm/ha	Cu gm/ha	Zn gm/ha	Mn gm/ha	Fe gm/ha
T_1	24.63	65.08	26.97	140.182	8.90	6.46	13.76	135.96
T_2	41.66	109.08	41.75	225.308	15.55	9.91	23.49	204.51
T_3	48.27	134.30	47.82	293.274	18.48	12.18	25.51	296.17
T_4	58.58	172.24	61.48	481.491	23.17	16.68	30.38	306.17
T_5	69.37	232.90	73.20	552.100	28.37	19.57	35.57	333.63
T_6	61.26	204.18	65.06	486.852	27.20	22.24	33.45	321.92
SEM ±	4.97	8.88	5.59	12.30	0.73	0.74	2.56	6.69
CD (0.05)	14.67	26.19	16.49	36.30	2.15	2.17	7.57	19.75
CV (%)	21.97	12.98	23.71	7.58	8.03	11.35	21.22	5.62

Micronutrient Uptake from onion bulb and leaves

A dose-dependent statistically significant micronutrient uptake was noted. However, uptake was also highest in T_5, with Cu, Zn, Mn, and Fe uptake at 69.37 gm/ha, 232.90 gm/ha, 73.20 gm/ha, and 552.10 gm/ha, respectively in bulbs (Table 5). These micronutrients also exhibited the same pattern in leaves, with the highest concentrations recorded in T_5 (Cu:28.37 gm/ha; Zn:19.57 gm/ha; Mn:35.57 gm/ha; Fe:333.63 gm/ha). The uptake of micronutrients was multiple times higher in bulbs compared to leaves. It might be because sulphur application positively affects nutrient availability by reducing soil pH, converting nutrients to more accessible forms for plant uptake, and enhancing soil physical conditions (Haneklaus *et al.,* 2007). The slight decrease in values for T_6 for all micronutrients of bulbs and leaves suggests excessive sulphur in T_6 may have led to nutrient saturation or potential antagonistic effects, reducing the efficiency of nutrient absorption (Chandel *et al.,* 2012).

CONCLUSION

The increase in nutrient content and uptake can be accredited to improved absorption and assimilation of micronutrients, which provide balanced nutrition for the crops. This, in turn, led to higher crop growth resulting in increased yield. In the present study, treatment T_5, which involved the application of 60 kg/ha of ES with RDF, was significantly superior to other treatments. T5-treated plants showed enhanced onion growth and yield. The same dose was noted as optimal for macronutrient and micronutrient contents uptake and retention.

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REFERENCES

Agricultural and Processed Food Products Export Development Authority (APEDA). (2024). https://apeda.gov.in/. Accessed on 21-08-2024.

Ariraman R, Kumar AP, Selvakumar S, Sowmya S, Mansingh MD. (2020). Effect of sulphur nutrition on growth parameters, yield parameters, yield, nutrient uptake, quality and economics of maize: A review. *Journal of Pharmacognosy and Phytochemistry.* **9**(6):1632-1636.

Badapmain Makdoh, A. P Singh, L. T. Longkumer, T. Gohain, Lanunola Tzudir, D. Nongmaithem, Rekha Yadav and L. Touthang (2023) Iron biofortification for enhancing yield, nutrient uptake and iron nutrition in soybean (Glycine max L.). *Annals of Plant and Soil Research*, **25**(2), 262-269.

Ballabh K, Rana DK. (2012). Response of micronutrients on qualitative and quantitative parameters of onion (*Allium cepa* L.). *Progressive Horticulture.* **44**(1):40-46.

Bertino NM, Grangeiro LC, Costa JP, Costa R, Lacerda RR, Gomes VE. (2022). Growth, nutrient accumulation, and yield of onion as a function of micronutrient fertilization. *Revista Brasileira de Engenharia Agrícola e Ambiental.* **26**:126-134.

Chandel BS, *et al.* (2012). Soil sulphur status and response of garlic to sulphur in relation to phosphorus. *Annals of Plant and Soil Research.* **14**:156-158.

Chandra N, Pandey N. (2021). Influence of sulphur-induced stress on oxidative status and antioxidative machinery in leaves of (*Allium cepa* L.). *International Scholarly Research Notices.* Article 9.

Channagoudar RF, Janawade AD. (2006). Effect of different levels of irrigation and sulphur on growth, yield and quality of onion (*Allium cepa* L.). *Karnataka Journal of Agricultural Sciences.* **19:**489-492.

Chattoo MA, Magray MM, Malik AA, Shah MD, Chisti JA. (2019). Effect of sources and levels of sulphur on growth, yield and quality of onion (*Allium cepa* L.). *International Journal of Current Microbiology and Applied Sciences.* **8**(3):1462-1470.

D'Souza LFG, Filho ABC, de Túlio FA, Nowaki RHD. (2015). Effect of sulphur dose on the productivity and quality of onions. *Australian Journal of Crop Science.* **9**:728-733.

Gurjar P, Tandon K, Lakhi R. (2019). Impact of sulphur, boron and its combinations on growth and yield of onion (*Allium cepa* L.). *Journal of Pharmacognosy and Phytochemistry.* **8**(3):1462-1470.

Haneklaus S, Bloem E, Schnug E. (2007). Sulphur interactions in crop ecosystems. In: Hawkesford MJ, De Kok LJ, editors. *Sulphur in plants: An ecological perspective.* Dordrecht, Netherlands: Springer. **4**: 17-58.

Katkar RN, Kharche VK, Lakhe SR, Deshmukh PR, Shukla AB, Tiwari P, Aage AB, Kadlag AD. (2017). Geographical information system-based micro and secondary nutrient mapping in soils of Maharashtra. Dr. PDKV, Akola. *Bulletin No.* **49***:1*:10.

Kaur BB, Sraw PK, Kaur A, Singh KS. (2017). Effect of potash and sulphur on yield and quality parameters under different planting methods in onion. *Journal of Applied and Natural Science.* **9**(4):2434-2437.

Klikocka H, Podleśna A, Podleśny J, Narolski B, Haneklaus S, Bloem E, Schnug E. (2019). Improvement of the content and uptake of micronutrients in spring rye grain DM through nitrogen and sulphur supplementation. *Agronomy.* **10**(1):35.

Meher R, *et al.* (2016). Effect of sulphur application in onion (*Allium cepa L.*). *Journal of Crop and Weed.* **12**(1):86-90.

Miller RO, Gavlak R, Horneck D. (2013). Soil, plant, and water reference methods for the western region (WREP-125), 4th ed. Fort Collins, CO: Colorado State University.

Mishu MH, Ahmed F, Rafii MY, Golam F, Latif MA. (2013). Effect of sulphur on growth, yield and yield attributes in onion (*Allium cepa* L.). *Australian Journal of Crop Science.* **7**(9):1416-1422.

Muhammad K, Dhaka AK, Singh B, Kamboj E, Rana A, Ravi. (2024). Impact of phosphorus and sulphur levels on growth parameters of groundnut (*Arachis hypogaea* L.). *Agricultural Science Digest.* doi: 10.18805/ag. d-5970.

Nadeem SM, Hanif A, Khan MY, Waqas MR, Ahmad Z, Ashraf MR, Naveed M. (2023). ES with sulphur oxidizing bacteria enhances phosphorus availability and improves growth and yield of wheat in calcareous soil. *Archives of Agronomy and Soil Science.* **69**(9):1494-1502.

National Horticulture Board (NHB). (2023). National Horticulture Database - 2023. Govt. of India, Gurugram, India. https://www.nhb.org.in/en/. Accessed on 21-08-2024.

Nivetha T, Uma K. (2020) Performance of fresh onions in India: An economic analysis. Journal of Chemical Studies. SP-**8**(4): 465-469

Panse VG, Sukhatme PV. (1995). Statistical methods for agricultural workers. New Delhi: Indian Council of Agricultural Research.

Pradhan R, *et al.* (2015). Influence of sulphur fertilization on nutrient uptake of onion (*Allium cepa L.*). *Journal of Crop and Weed.* **11**:134-138.

Ram A, Kumar D, Singh N, Anand A. (2014). Effect of sulphur on growth, productivity, and economics of aerobic rice (*Oryza sativa*). *Indian Journal of Agronomy.* **59**(3):404-409.

Rathod PH, *et al.* (2020). Effect of sulphur and zinc-containing customized fertilizers on growth, yield, and nutrient uptake of onion. *International Journal of Current Microbiology and Applied Sciences.* **9**(1).

Rizk FA, Shaheen AM, El-Samad EHA, Sawan OM. (2012). Effect of different nitrogen plus phosphorus and sulphur fertilizer levels on growth, yield, and quality of onion (*Allium cepa* L.). *Journal of Applied Sciences Research.* **8**(7):3353-3361.

Shukla AK, Tiwari P, Sidhiqqui S, Patra AK, Choudhary SK. (2016). Micro and secondary nutrients in Indian soils: Condition of deficiency, prevention, and recommendations. *Indian Institute of Soil Science.* **3**:25.

Singh S. (2017). Effect of sulphur nutrition on productivity, nutrient uptake and economics of pearl millet (Pennisetum glaucum)-Indian mustard (*Brassica juncea*) cropping system. *Indian Journal of Agricultural Sciences.* **87**(1):69-73.

Singh U.N., Pandey M, Singh O. (2020) Soil sulphur status and response of onion (*Allium cepa* L.) to sources and levels of sulphur. *Annals of Plant and Soil Research.* **22**(2):115-118.Singh, U.,

Tomar, S., Rameshwar, S., & Choudhary, S. (2015) Yield, nutrient uptake and economics of Indian mustard as influenced by varieties, sources and levels of sulphur. *Annals of Plant and Soil Research*, ***17***(3), 266-268.

Sisodiya RR, Babaria NB, Parmar TN, Parmara KB. (2017) Effect of sources and levels of sulphur on yield and micronutrient (Fe, Mn, Zn, and Cu) absorption by groundnut (*Arachis hypogaea* L.). *International Journal of Agricultural Sciences.* **9**(5):4465-4467.

Soaud AA, Al Darwish FH, Saleh ME, El-Tarabily KA, Sofian-Azirun M, Rahman MM. (2011) Effects of ES, phosphorus, micronutrients, and Paracoccus versutus on nutrient availability of calcareous soils. *Australian Journal of Crop Science.* **5**(5):554-561.

Tandon HLS, Messick DL. (2002). Practical sulphur guide. Washington, DC: Sulphur Institute.

Tripathy P, Sahoo BB, Priyadarshini A, Das SK, Dash DK. (2013) Effect of sources and levels of sulphur on growth, yield, and bulb quality in onion (*Allium cepa* L.). *International Journal of Bio-resource and Stress Management.* **4**:641-644.

Uikey D, Chittora AB, Birla D, Taneb K. (2015) Effect of potassium and sulphur on growth, yield, and quality of onion. *Annals of Plant and Soil Research.* **17**(4):356-361.

Verma S, Choudhary MR, Yadav BL, Jakhar ML. (2013) Influence of vermicompost and sulphur on growth and yield of garlic (*Allium sativum L.*) under semi-arid climate. *Journal of Spices and Aromatic Crops.* **22**(1):20-23.

Zahed Z, Kumar SS, Mahale AG, Krishna JR, Mufti S. (2021) Foliar micro-nutrition of vegetable crops: A critical review. *Current Journal of Applied Science and Technology.* **40**(7):1-2.