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Effect of Sulphur, Zinc and Boron on Nutrient Uptake and Economics of Chilli (*Capsicum annuum* L.) in *Vertisol*

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted at the farmers field in Auard village of Jewargi taluk in Kalaburagi district of Karnataka state during *Kharif* 2024 to study the effect of sulphur, zinc and boron on the yield and quality of chilli in *Vertisol*. The experiment was laid out in a RCBD with ten treatments replicated thrice. The results revealed that the application of 100% RDF + sulphur @ 30 kg ha^{-1} through bentonite sulphur (90%) + 0.1% zinc EDTA (12%) + 0.2% Solubor (19%) as foliar spray at flower initiation (45 days), flowering (60 days) and fruiting (75 days) stages recorded significantly higher nutrient uptake and economics viz. nitrogen, phosphorus, potassium, sulphur, zinc and boron uptake and was statistically on par with 100% RDF + sulphur @ 20 kg ha^{-1} through bentonite sulphur (90%) + 0.05% zinc EDTA (12%) + 0.1% Solubor (19%) foliar spray at the same stages while the lowest values were recorded in control.

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Keywords: Chilli; foliar application; sulphur; zinc and boron; nutrient uptake.

1. INTRODUCTION

Dry chilli (*Capsicum annuum* L.) is an important spice crop grown for its pungency, flavour and deep red colour, widely used in culinary, pharmaceutical and cosmetic industries. It serves as a rich source of nutrients and bioactive compounds such as capsaicin, oleoresin and carotenoids, which contribute to its commercial and nutritional significance. In India, dry chilli fetches a high market value in both domestic and export sectors. According to Devi et al. (2018), 100 g of dry chilli contains 8.8% moisture, 15.9 g protein, 6.0 g fat, 54.0 g carbohydrate, 160 mg calcium, 90 mg phosphorus and 76.0 mg ascorbic acid.

Sulphur is the fourth major plant nutrient after nitrogen, phosphorus and potassium. It is vital for protein formation, chlorophyll synthesis, root growth, and enzyme and vitamin production. Deficiency reduces protein synthesis, chlorophyll content and overall plant development. Sulphur deficiency limits crop growth even with NPK application (Surendra and Singh, 2008).

Zinc is an essential micronutrient for plants, animals and humans. It regulates physiological growth, DNA stabilization, gene expression, enzyme activity, protein synthesis, and chlorophyll function. Zinc deficiency is a major yield-limiting factor, ranking third after nitrogen and phosphorus. In India, 83% of soils are zinc deficient, restricting crop production.

Boron is a crucial micronutrient regulating cell division, elongation, crop growth, yield and quality. It supports meristem development, pollination, fruit and seed set, sugar translocation, amino acid synthesis, protein formation, nutrient movement, hormone regulation and cell-wall formation. Deficiency affects crops in India, China, Nepal and Bangladesh (Shireen et al., 2018 and Shorrocks, 1997).

Vertisol clay-rich soils, with high moisture holding capacity and swelling-shrinking behaviour, support sustained chilli growth by enhancing water retention, nutrient availability and rooting depth, though requiring careful aeration (Virmani et al., 1982). Optimum sulphur through soil application and foliar zinc and boron improve growth, yield and quality as foliar feeding delivers nutrients directly and rapidly to plant tissues (Baloch et al., 2008). With this background above experiment was taken with an objective of effect of Sulphur, Zinc and Boron on Nutrient uptake and Economics of chilli.

2. MATERIALS AND METHODS

The experiment was conducted during *Kharif* 2024 at the farmers field in Auard village of Jewargi taluk in Kalaburagi District of Karnataka state, situated in the North Eastern Dry Zone (Zone-2) of Karnataka at a latitude of 16˚96' N, longitude of 76˚77' E, and an altitude of 449.43 meters above mean sea level. The soil at the experimental site was medium deep clay in texture.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications and ten treatments, which included Control (T_1), RDF* (150:75:75; N: P_2O_5: K_2O kg ha^{-1}) (T_2), 100% RDF + Sulphur @ 20 kg ha^{-1} through Bentonite sulphur (90%) (T_3), 100% RDF + Sulphur @ 30 kg ha^{-1} through Bentonite sulphur (90%) (T_4), 100% RDF + 0.05% Zinc EDTA (12%) foliar spray at flower initiation (45 days), flowering (60 days) and fruiting (75 days) (T_5), 100% RDF + 0.1% Zinc EDTA (12%) foliar spray at the same stages (T_6), 100% RDF + 0.1% Solubor (19%) foliar spray at the same stages (T_7), 100% RDF + 0.2% Solubor (19%) foliar spray at the same stages (T_8), 100% RDF + Sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1% Solubor foliar spray at the same stages (T_9) and 100% RDF + Sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor foliar spray at the same stages (T_{10}). The chilli hybrid used was OM-3, a high-yielding variety, planted with a spacing of 90 cm × 90 cm. The study was conducted to evaluate the effect of sulphur, zinc and boron on nutrient uptake and economics of chilli. The nutrients were analysed as per standard procedures.

3. RESULTS AND DISCUSSION

3.1 Uptake of Nitrogen (Kg ha^{-1})

The influence of different levels of sulphur, zinc and boron had a significant effect on nitrogen uptake by the chilli plant. The highest nitrogen uptake (92.82 kg ha^{-1}) was observed in treatment T_{10} (RDF + sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor), which was statistically on par with T_9 (90.45 kg ha^{-1}) receiving RDF + sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1%

Solubor. The lowest nitrogen uptake was recorded in the control treatment T_1 (32.69 kg ha^{-1}), which received no additional sulphur, zinc, or boron. Application of sulphur, zinc and boron in chilli enhances nitrogen uptake by promoting synergistic root proliferation, enzyme stimulation and N assimilation pathways. Nawrin et al. (2020) both reported improved nitrogen absorption and vegetative vigour in chilli under combined micronutrient regimes.

3.2 Uptake of Phosphorus (Kg ha^{-1})

The influence of different levels of sulphur, zinc and boron had a significant effect on phosphorus uptake by the chilli plant. The highest phosphorus uptake (10.15 kg ha^{-1}) was observed in treatment T_{10} (RDF + sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor), which was statistically on par with T_9 (9.54 kg ha^{-1}) receiving RDF + sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1% Solubor. The lowest phosphorus uptake was recorded in the control treatment T_1 (1.61 kg ha^{-1}), which received no additional sulphur, zinc, or boron. Combined application of S, Zn and B significantly boosts phosphorus uptake in chilli by improving root development, phosphatase activity, and nutrient translocation efficiency. Gokul et al. (2025) and Islam et al. (2018) documented increased phosphorus availability and enhanced P-use efficiency with balanced micronutrient treatment.

3.3 Uptake of Potassium (kg ha^{-1})

The influence of different levels of sulphur, zinc and boron had a significant effect on potassium uptake by the chilli plant. The highest potassium uptake (89.14 kg ha^{-1}) was observed in treatment T_{10} (RDF + sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor), which was statistically on par with T_9 (87.68 kg ha^{-1}) receiving RDF + sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1% Solubor. The lowest potassium uptake was recorded in the control treatment T_1 (33.20 kg ha^{-1}), which received no additional sulphur, zinc, or boron. Application of sulphur, zinc and boron in chilli has been shown to enhance potassium uptake by improving root activity, membrane permeability and overall nutrient transport. and Koraprolu (2007) reported that balanced nutrient application, including micronutrients like S, Zn and B, significantly improved K absorption and plant performance in chilli.

3.4 Uptake of Sulphur (kg ha^{-1})

The influence of different levels of sulphur, zinc and boron had a significant effect on sulphur uptake by the chilli plant. The highest sulphur uptake (18.22 kg ha^{-1}) was observed in treatment T_{10} (RDF + sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor), which was statistically on par with T_9 (17.33 kg ha^{-1}) receiving RDF + sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1% Solubor. The lowest sulphur uptake was recorded in the control treatment T_1 (3.66 kg ha^{-1}), which received no additional sulphur, zinc, or boron. This may be due to the synergistic interaction between sulphur and zinc, where each nutrient enhances the uptake and utilization of the other. These results are supported by the findings of Gokul et al. (2025) and Malik et al. (2020).

3.5 Uptake of Zinc (g ha^{-1})

The influence of different levels of sulphur, zinc and boron had a significant effect on zinc uptake by the chilli plant. The highest zinc uptake (93.94 g ha^{-1}) was observed in treatment T_{10} (RDF + sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor), which was statistically on par with T_9 (89.89 g ha^{-1}) receiving RDF + sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1% Solubor. The lowest zinc uptake was recorded in the control treatment T_1 (24.61 g ha^{-1}), which received no additional sulphur, zinc, or boron. Application of sulphur, zinc and boron in chilli enhanced zinc uptake, which may be attributed to zinc's vital role in chlorophyll formation, auxin regulation and enzyme activation, all of which support efficient nutrient absorption. The synergistic interaction between sulphur, zinc and boron likely improved nutrient mobility and uptake efficiency. Similarly, the present findings are consistent with the results of Kumar and Singh (1979).

3.6 Uptake of Boron (g ha^{-1})

The influence of different levels of sulphur, zinc and boron had a significant effect on boron uptake by the chilli plant. The highest boron uptake (68.57 g ha^{-1}) was observed in treatment T_{10} (RDF + sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor), which was statistically on par with T_9 (66.05 g ha^{-1}) receiving RDF + sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1% Solubor. The lowest boron uptake was recorded in the control treatment T_1 (18.66 g ha^{-1}), which received no additional sulphur, zinc or boron. Application of sulphur, zinc and boron in chilli significantly enhanced boron uptake by improving chlorophyll content and photosynthetic efficiency. Increased assimilate production promoted root growth, facilitating better boron

Table 1. Effect of different levels of sulphur, zinc and boron on uptake of nutrients in plant samples after the harvest of dry chilli crop

Treatment		Nutrients uptake					
		N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (kg ha^{-1})	Zn (g ha^{-1})	B (g ha^{-1})
T_1	Control	32.69	1.61	33.20	3.66	24.61	18.66
T_2	RDF	47.76	3.21	45.83	5.74	39.96	29.72
T_3	RDF + sulphur @ 20 kgha^{-1}	68.14	6.55	64.74	11.62	58.15	43.97
T_4	RDF + sulphur @ 30 kgha^{-1}	72.93	7.63	69.76	12.12	61.58	48.72
T_5	RDF + 0.05 % Zinc EDTA	61.68	4.89	58.38	8.95	68.55	41.01
T_6	RDF + 0.1 % Zinc EDTA	71.62	7.16	67.49	10.35	74.16	46.46
T_7	RDF + 0.1 % Solubor	65.32	5.92	61.95	9.91	53.39	51.31
T_8	RDF + 0.2 % Solubor	76.28	8.03	72.26	11.11	65.52	53.71
T_9	RDF + sulphur @ 20 kgha^{-1} + 0.05 % Zinc EDTA + 0.1 % Solubor	90.45	9.54	87.68	17.33	89.89	66.05
T_{10}	RDF + sulphur @ 30 kgha^{-1} + 0.1 % Zinc EDTA+ 0.2 % Solubor	92.82	10.15	89.14	18.22	93.94	68.57
S.Em. ±		4.26	0.24	2.24	0.38	2.34	1.62
CD @ 5%		12.67	0.70	6.67	1.12	6.95	4.82

Note:

1. *Sulphur is supplied in the form of Bentonite sulphur (90 % S)*
2. *Zinc is supplied in the form of Zinc EDTA (12%) foliar spray at flower initiation (45 days), flowering (60 days) and fruiting stages (75 days)*
3. *Boron is supplied in the form of Solubor (19 %) foliar spray at flower initiation stage (45 days), flowering (60 days) and fruiting stages (75 days)*
4. *Recommended dose of fertilizer (RDF) 150:75:75; N: P_2O_5: K_2O; kg ha^{-1} (Based on soil test values basis) + FYM @ 25 tonnes ha^{-1}*

Table 2. Effect of different levels of sulphur, zinc and boron on economics of dry chilli crop cultivation

Treatments		Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
T_1	Control	77750	316242	238492	4.07
T_2	RDF	88205	456950	368745	5.18
T_3	RDF + sulphur @ 20 kgha^{-1}	89415	494950	405535	5.54
T_4	RDF + sulphur @ 30 kgha^{-1}	90020	501600	411580	5.57
T_5	RDF + 0.05 % Zinc EDTA	88408	488300	399892	5.52
T_6	RDF + 0.1 % Zinc EDTA	88611	497800	409189	5.62
T_7	RDF + 0.1 % Solubor	88805	492100	403295	5.54
T_8	RDF + 0.2 % Solubor	89405	504450	415045	5.64
T_9	RDF + sulphur @ 20 kgha^{-1} + 0.05 % Zinc EDTA + 0.1 % Solubor	90218	535800	445582	5.94
T_{10}	RDF + sulphur @ 30 kgha^{-1} + 0.1 % Zinc EDTA+ 0.2 % Solubor	91626	539600	447974	5.89
S.Em. ±		-	9915.7	9915.7	0.08
CD @ 5%		-	29461.1	29461.1	0.25

Note:

1. *Sulphur is supplied in the form of Bentonite sulphur (90 % S)*
2. *Zinc is supplied in the form of Zinc EDTA (12%) foliar spray at flower initiation (45 days), flowering (60 days) and fruiting stages (75 days)*
3. *Boron is supplied in the form of Solubor (19 %) foliar spray at flower initiation stage (45 days), flowering (60 days) and fruiting stages (75 days)*
4. *Recommended dose of fertilizer (RDF) 150:75:75; N: P_2O_5: K_2O; kg ha^{-1} (Based on soil test values basis) + FYM @ 25 tonnes ha^{-1}*

absorption. Similarly, the present findings are consistent with the results of Yadav et al. (2023).

3.7 Economics

3.7.1 Gross and net returns

The economic analysis revealed that the treatment comprising RDF + sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor (T_{10}) resulted in the highest profitability, with gross returns (₹539600 ha^{-1}) and net returns of (₹447974 ha^{-1}). This was statistically comparable to the treatment RDF + sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1% Solubor (T_9), which recorded gross and net returns (₹ 535800 ha^{-1}) and (₹ 445582 ha^{-1}), respectively. In contrast, the lowest economic returns were observed in the control plot (T_1), which received no sulphur, zinc, or boron, resulting in gross returns (₹ 316242 ha^{-1}) and net returns (₹ 238492 ha^{-1}).The highest net returns recorded with 30 kg S ha^{-1}, 1% Zn and 0.2% B (T_{10}) was attributed to higher fruit yield (Table 2) resulting in highest gross returns (₹ 539600 ha^{-1}). Similar results were also reported by Dubey et al. (2013)

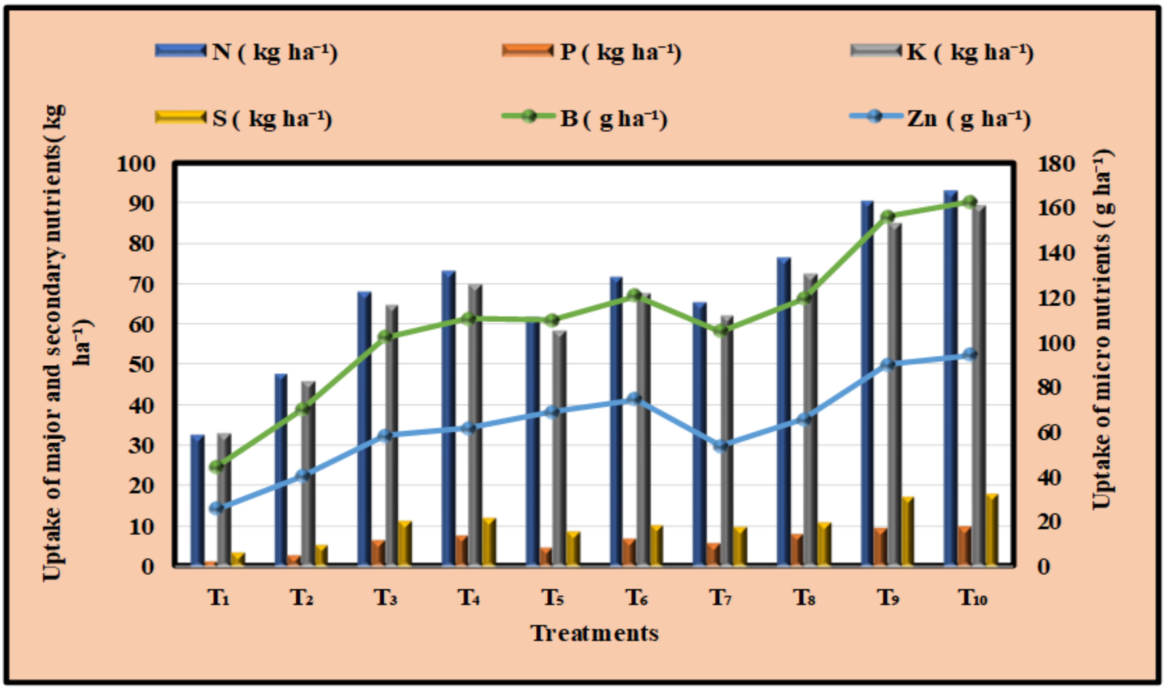

Fig. 1. Graph showing Effect of different levels of sulphur, zinc and boron on nutrient uptake of dry chilli crop

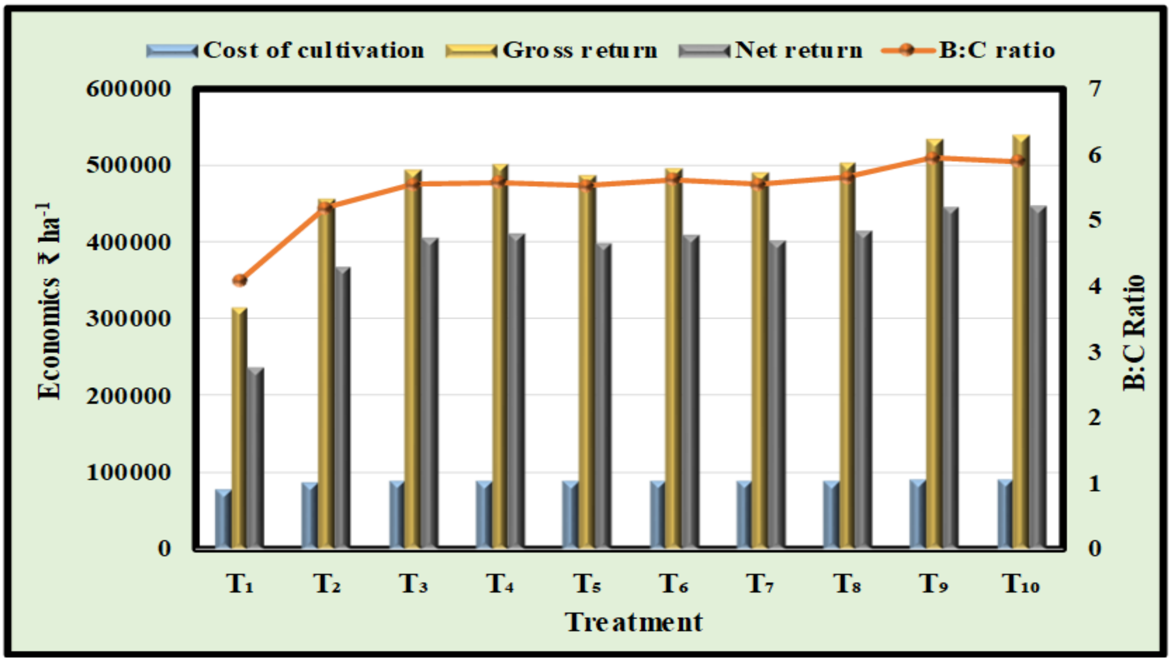

Fig. 2. Graph showing Effect of different levels of sulphur, zinc and boron on economics of drychilli crop

3.7.2 Benefit:cost ratio

The economic analysis revealed that the treatment with RDF + sulphur @ 20 kg ha^{-1} + 0.05% Zinc EDTA + 0.1% Solubor (T_9) resulted in a benefit-cost ratio (5.89). This was statistically on par with treatment RDF + sulphur @ 30 kg ha^{-1} + 0.1% Zinc EDTA + 0.2% Solubor (T_{10}), which recorded a B:C ratio of (5.94). In contrast, the lowest B:C ratio was observed in the control plot (T_1), which received no sulphur, zinc or boron, resulting a B:C ratio only (4.07). Similar results were also reported by Devi et al. (2018)

4. CONCLUSION

Based on the results obtained under present investigation, it can be concluded that soil application of sulphur (20 kg ha^{-1})through bentonite sulphur @ 22 kg ha^{-1}, foliar application of zinc EDTA (0.05%) @ 0.75 kg ha^{-1} and foliar spray of solubor (0.1%)@ 1.5 kg ha^{-1} along with recommended dose of fertilizers was found superior not only in increasing the nutrient uptake but also improved economics of chilli crop.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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