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Effect of Nano-fertilizers and Micronutrient Applications on Yield and Economics of Tomato (*Lycopersicon esculentum* Mill.) cv. Heemsohna

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Authors' contributions

This work was carried out in collaboration among all authors. Authors RKS and VB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SKM and AS managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study investigates the impact of nano-fertilizers and micronutrient applications on the fresh yield and economic returns of tomato (*Lycopersicon esculentum* Mill.) cv. Heemsohna under field conditions.
Place, Duration and Study Design: This experiment was conducted at Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj, across two summer growing seasons

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(2021-22 and 2022-23), the experiment employed a factorial randomized block design with 20 treatment combinations, including varying foliar applications of Nano-NPK and nano-mixed micronutrients.

Results: Results indicated that the application of Nano-NPK (4 ml/liter) significantly enhanced fruit set, weight, and overall yield, with nano-boron and nano-zinc further boosting fruit quality. The treatment combination F_2M_3 (Nano-NPK at 5 ml/liter with nano micronutrients at 6 ml/liter) yielded the highest productivity (93.94 t/ha) and was economically most viable, achieving a benefit-cost ratio of 6.42.

Conclusion: The findings underscore the potential of nano-fertilizers to improve nutrient-use efficiency, supporting sustainable tomato production by optimizing yield and profitability.

Keywords: Tomato; nano-NPK; nano-mix fertilizer; yield; economics.

1. INTRODUCTION

Tomato (*Solanum lycopersicum* Mill.) belongs to the family Solanaceae is a major horticultural crop cultivated globally, valued for its economic and nutritional importance (Kumar et al., 2020). It plays a significant role in both fresh consumption and as a key ingredient in processed products. The fruit's popularity is due to its adaptability, high productivity, and nutritional composition, making it a vital crop for both large-scale agriculture and smallholder farmers (Lanjwani et al., 2024). As global demand for tomatoes increases, improving yield and fruit quality remains a central goal for researchers and farmers alike (Grieneisen et al., 2018). Both yield and quality are influenced by several factors, including cultivar selection, environmental conditions, and nutrient management.

Nutrient management is critical for tomato production, as tomatoes are considered heavy feeders that demand an adequate supply of macro- and micronutrients to reach optimal yield and quality. Nitrogen (N), phosphorus (P), and potassium (K) are the primary macronutrients essential for plant growth (Jat et al., 2023; Jat et al., 2024a). Nitrogen, in particular, is crucial for vegetative growth and plays a vital role in chlorophyll production, which directly affects photosynthesis and overall plant health (Simkin et al., 2022; Jat et al., 2024b). Phosphorus is involved in energy transfer and root development, while potassium enhances fruit size, color, and taste by regulating water uptake and improving stress tolerance (Sinha and Tandon, 2020). Recent advancements in nanotechnology have introduced nano-fertilizers as an innovative approach to nutrient management. Nano-fertilizers have gained attention for their potential to improve nutrient-use efficiency and enhance plant growth and yield. They provide controlled release of nutrients, reducing leaching and improving absorption by plants (Iqbal et al., 2019). This is particularly relevant for tomatoes, which are highly sensitive to nutrient deficiencies that can affect both yield and fruit quality. Studies have shown that the application of nano-fertilizers can significantly improve the availability of essential nutrients, leading to higher productivity and better-quality fruits (Almohammedi et al., 2023). For example, nano-forms of nutrients such as zinc and boron have been found to enhance enzymatic activities that promote growth and improve the nutritional content of tomato fruits. In addition to macronutrients, micronutrients like zinc and boron play crucial roles in plant physiology, directly influencing yield and quality. Zinc is involved in the synthesis of proteins and nucleic acids, while boron is essential for reproductive development and fruit set (Jat et al., 2024b). Deficiencies in these micronutrients can lead to poor fruit quality, characterized by reduced size, uneven ripening, and low nutrient content. Therefore, the application of both macro- and micronutrients is necessary for ensuring high yields of marketable tomatoes.

Yield parameters in tomatoes are influenced by several factors, including the balance of nutrients, soil fertility, and external growing conditions. Yield is typically measured in terms of fruit weight, number of fruits per plant, and overall productivity per hectare. The application of nano-fertilizers offers promising results in improving both yield and quality parameters (El-Saadony et al., 2021). For example, nano-nitrogen fertilizers have been shown to promote more efficient nitrogen uptake, leading to improved vegetative growth and higher fruit yields. Similarly, the use of nano-zinc has been linked to increased fruit size and enhanced antioxidant levels, contributing to better marketability and nutritional value (Saini et al., 2023). Nano-boron, in particular, improves fruit set and reduces the incidence of fruit deformities, ensuring a more consistent and higher-quality yield. However, the adoption of nano-fertilizers in agriculture also presents challenges. The long-term effects of these fertilizers on soil fertility and the environment are still being studied. Some concerns have been raised about the potential for nano-particle accumulation in the soil and its impact on soil microbes and plant physiology. Therefore, while nano-fertilizers offer significant potential for enhancing tomato production, further research is needed to optimize their application methods and minimize any potential risks. In conclusion, improving the yield and quality of tomato production requires a comprehensive nutrient management strategy that incorporates both macro- and micronutrients. Nano-fertilizers represent an exciting innovation in this field, offering the potential for more efficient nutrient use and higher-quality yields. By addressing nutrient deficiencies more effectively and reducing environmental impacts, nano-fertilizers can play a key role in sustainable tomato production. This study aims to investigate the effects of nano-fertilizers and micronutrients on the yield and economic feasibility of tomato (*Lycopersicon esculentum* Mill.) cv. Heemsohna under field conditions.

2. MATERIALS AND METHODS

2.1 Experimental Site and Treatments Detail

This experiment was conducted at the Departmental Research Region of Horticulture Department, Naini Agricultural Institute of the Sam Higginbottom University of Agricultural Technology and Sciences in Prayagraj, Uttar Pradesh, in summer season of 2021-22 and 2022-23. The experiment was designed in a factorial randomized block design consisting of two factors with 3 replications. The twenty treatment combinations were allocated randomly to each plot so that each plot received only one treatment within the replication during both years of experimentation on tomato cv. Heemsonha. Three-four weeks old seedlings were transplanted at a spacing of 60 cm × 45 cm. Transplanting was done on 15th November, 2021 and 15th November, 2022.

Table 1. Detail of the treatment combinations used during the experimentation

Sr. No.	Treatment symbol	Combination
1.	T_1	Control
2.	T_2	100% RDF as traditional fertilizer
3.	T_3	5ml each of Nano NPK/lit. of water as foliar application
4.	T_4	4ml each of Nano-NPK/ lit. of water as foliar application
5.	T_5	3ml each of nano-NPK/lit. of water as foliar application
6.	T_6	2ml of nano-mix micronutrient/ lit. of water as foliar application
7.	T_7	4ml of nano-mix micronutrient/ lit. of water as foliar application
8.	T8	6ml of nano-mix micronutrient / lit. of water as foliar application
9.	T_9	100% RDF as traditional fertilizer + 2ml of nano-mix micronutrient/ lit. of water as foliar application
10.	T_{10}	100% RDF as traditional fertilizer + 4ml of nano-mix micronutrient/ lit. of water as foliar application
11.	T_{11}	100% RDF as traditional fertilizer + 6ml of nano-mix micronutrient / lit. of water as foliar application
12.	T_{12}	5ml each of Nano-NPK of water as foliar application + 2ml/ lit. of nano-mix micronutrient of water as foliar application
13.	T_{13}	5ml each of Nano-NPK of water as foliar application+ 4ml of nano-mix micronutrient/ lit. of water as foliar application
14.	T_{14}	5ml each of Nano-NPK of water as foliar application+ 6ml of nano-mix micronutrient / lit. of water as foliar application
15.	T_{15}	4ml each of Nano-NPK/lit. of water as foliar application + 2ml of nano-mix micronutrient/ lit. of water as foliar application
16.	T_{16}	4ml each of Nano-NPK/ lit. of water as foliar application+ 4ml of nano-mix micronutrient/ lit. of water as foliar application
17.	T_{17}	4ml each of Nano-NPK/ lit. of water as foliar application+ 6ml of nano-mix micronutrient / lit. of water as foliar application
18.	T_{18}	3ml each of Nano-NPK/ lit. of water as foliar application + 2ml of nano-mix micronutrient/ lit. of water as foliar application
19.	T_{19}	3ml each of Nano-NPK/ lit. of water as foliar application+ 4ml of nano-mix micronutrient/ lit. of water as foliar application
20	T_{20}	3ml each of Nano-NPK/ lit. of water as foliar application + 6ml of nano-mix micronutrient / lit. of water as foliar application

2.2 Observations Recorded

The observations were recorded on five randomly selected plants in each plot. Data were collected in accordance with standard procedures as follows: after fruit setting, the total number of fruit set on five selected plants was averaged. A total number of fruits per plant was calculated by averaging the fruits harvested from five selected plants at each harvest. The weight of five fruits was recorded in gram from five randomly selected plants of each treatment in each replication and then averaged. Five plants from each treatment were selected for fruit picking. Each plant's yield was averaged and expressed as a yield per plant. Fruit yield per hectare (t) was calculated from the figure of fruit yield per plant or fruit yield per plot.

2.3 Statistical Analysis

Statistical analysis was conducted using Factorial Randomized Block Design (FRBD) as described by Snedecor and Cochran, 1987.

3. RESULTS AND DISCUSSION

The effect of nano-fertilizers and nano-mix micronutrients on tomato fruit set, fruit weight, fruit yield, and economic parameters over the two years (2021 and 2022) is summarized in Tables from 2a to 3b. The analysis demonstrated significant improvements in the number of fruits set per plant, fruit weight, yield and profitability with the application of nano-fertilizers, particularly when combined with nano-mix micronutrients.

The application of nano-NPK significantly increased the number of fruit sets per plant during both years (Table 2a). The highest number of fruit sets was observed with the F_3- 4ml each of Nano-NPK/ lit. of water as Foliar application treatment (49.04 and 53.70 in 2021 and 2022, respectively), followed by F_4- 3ml each of Nano-NPK/ lit. of water as FA (47.93 and 52.83), both significantly superior to the control (F_0). The combination of nano-mixed micronutrients also showed an influence, with the highest number of fruit sets recorded with M_3- 6ml of nano-mix micronutrient / lit. of water as FA (46.65 and 51.33 in 2021 and 2022, respectively). However, the interaction effects of nano-NPK and nano-mixed micronutrient (Table 2b) further revealed that the F_2M_3 combination achieved the maximum number of fruit sets (44.87 in 2021 and 48.22 in 2022). This may be attributed to better synthesis of cytokinin with optimum supply of N and P resulting in a greater number of flowers and fruits (Premsekhar and Rajashree, 2009). There are also reports on higher fruit setting by soil or foliar supplementation of secondary and micro nutrients which may be attributed to supply of nutrients at critical stage *i.e*. at flowering and fruit set (Raj et al., 2019). Nano micronutrients such as boron are responsible for pollination, the formation of pollen tube and also for fruit set. Similar findings were reported by El-Desouky et al. (2021) in tomato.

The fruit weight was significantly influenced by both nano-NPK and nano-mixed micronutrients (Table 2a). The treatment F_3- 4ml each of Nano-NPK/ lit. of water as FA treatment produced the heaviest fruits (80.36 g and 86.64 g in 2021 and 2022, respectively): it was closely followed by treatment F_4- 3ml each of Nano-NPK/ lit. of water as FA. The nano-mixed micronutrient treatment M_3- 6ml of nano-mix micronutrient/ lit. of water as FA also resulted in significantly higher fruit weights compared to the control (M_0). The interaction of F_2M_3 again showed the most pronounced effects, with fruit weights reaching 84.67 g in 2021 and 87.67 g in 2022 (Table 2b).

Nano fertilizers and micronutrients had a profound impact on the total fruit weight per plant and yield per hectare (Table 3a). The F_3 - 4ml each of Nano-NPK/ lit. of water as FA treatment revealed the highest fruit weight per plant (3.36 kg in 2021 and 3.89 kg in 2022) and the maximum fruit yield (74.72 t/ha in 2021 and 86.43 t/ha in 2022), indicating a substantial yield improvement compared to the control (F_0). Among micronutrient treatments, M_3- 6ml of nano-mix micronutrient / lit. of water as FA led to the highest yield (60.44 t/ha in 2021 and 73.65 t/ha in 2022). The interaction effects (Table 3b) showed that the F_2M_3 treatment recorded the maximum yield, reaching 84.43 t/ha in 2021 and 93.94 t/ha in 2022, indicating a synergistic effect of nano-NPK and micronutrient applications.

The significant increase in the number of fruit sets and fruit weight with nano-NPK and nano-mixed micronutrient application can be attributed to enhanced nutrient uptake efficiency, improved photosynthetic activity, and the synergistic effects of micronutrients. Nano-NPK fertilizers, particularly at 4ml/L(F_3), provide nano-sized particles that increase the surface area for better nutrient absorption, boosting nitrogen, phosphorus, and potassium uptake—critical elements for growth, flowering, and fruit development (Semenova et al., 2024). The application of nano-NPK likely enhanced chlorophyll synthesis and photosynthetic efficiency, resulting in better carbohydrate availability for fruit growth, which explains the increase in fruit weight (Abd-Elrahman et al., 2023). Furthermore, nano micronutrients, especially in the M_3 treatment, supplemented essential trace elements that support enzymatic functions and hormonal regulation, contributing to the overall improvement in yield. The interaction of these factors, particularly in the F_2M_3 combination, highlights the synergistic effect of combining nano-NPK with micronutrients, resulting in the highest number of fruit sets and yield per hectare.

Table 2a. Effect of nano-fertilizer and nano-mixed micronutrient on number of fruit set and fruit weight of tomato

Treatments	Number of fruit set/ plant		Fruit weight (g)	
	2021	**2022**	**2021**	**2022**
Factor A: Nano-NPK				
F_0	43.46	47.80	68.79	76.05
F_1	43.86	47.83	68.87	76.25
F_2	45.52	49.78	72.69	81.14
F_3	49.04	53.70	80.36	86.64
F_4	47.93	52.83	76.11	85.76
SEm±	0.38	0.44	0.54	0.57
LSD at 5 %	1.09	1.27	1.56	1.63
Factor B: Nano-mix micronutrient				
M_0	45.77	50.17	72.99	79.70
M_1	45.59	49.84	73.36	79.91
M_2	45.83	50.21	73.09	81.80
M_3	46.65	51.33	74.02	83.26
SEm±	0.34	0.40	0.49	0.51
LSD at 5 %	NS	NS	NS	1.46
Interaction A × B				
SEm±	0.76	0.89	1.09	1.13
LSD at 5 %	2.17	2.55	3.12	3.25

Note: F_0 – Control (without fertilizer), F_1- 100% Recommended Dose of Fertilizers as traditional fertilizer, F_2- 5ml each of Nano-NPK/ lit. of water as FA, F_3- 4ml each of Nano-NPK/ lit. of water as FA, F_4- 3ml each of Nano-NPK/ lit. of water as FA, M_0- control (without micronutrient), M_1- 2ml of nano-mix micronutrient/ lit. of water as FA, M_2- 4ml of nano-mix micronutrient/ lit. of water as FA, M_3- 6ml of nano-mix micronutrient / lit. of water as FA

Table 2b. Interaction effect of nano-fertilizer and nano-mixed micronutrient on number of fruit set and fruit weight of tomato

Treatment combinations	Number of fruit set/ plant		Fruit weight (g)	
	2021	**2022**	**2021**	**2022**
F_0M_0	25.01	28.68	66.00	72.00
F_1M_0	25.95	29.20	67.50	73.67
F_2M_0	32.43	35.65	71.34	79.56
F_3M_0	31.70	34.43	70.33	78.98
F_4M_0	27.33	31.40	68.54	75.00
F_0M_1	26.95	30.20	67.83	74.67
F_0M_2	29.29	32.62	69.33	77.33
F_0M_3	30.45	33.56	69.76	78.00
F_1M_1	28.54	31.87	69.10	76.67
F_1M_2	33.09	36.26	72.65	80.67
F_1M_3	34.53	37.17	73.00	81.56
F_2M_1	38.26	41.89	76.00	85.67
F_2M_2	43.05	46.63	84.00	87.67
F_2M_3	44.87	48.22	84.67	87.67
F_3M_1	37.30	39.78	75.43	84.23
F_3M_2	41.65	44.73	77.33	87.00
F_3M_3	42.20	45.32	77.33	87.17
F_4M_1	35.42	38.66	74.12	82.87
F_4M_2	39.93	42.72	76.33	86.33
F_4M_3	40.65	43.32	76.67	86.67
SEm±	0.48	0.56	1.09	1.13
LSD at 5 %	1.39	1.62	3.12	3.25

Table 3a. Effect of nano-fertilizer and nano-mixed micronutrient on fruit weight per plant and yield of tomato

Treatments	Fruit weight (kg/ plant)		Fruit yield/ha (t)	
	2021	2022	2021	2022
Factor A: Nano-NPK				
F_0	1.99	2.44	44.14	54.29
F_1	1.96	2.44	43.64	54.17
F_2	2.45	3.00	54.47	66.60
F_3	3.36	3.89	74.72	86.43
F_4	3.01	3.65	66.96	81.09
SEm±	0.02	0.03	0.54	0.45
LSD at 5 %	0.07	0.07	1.55	1.31
Factor B: Nano-mix micronutrient				
M_0	2.48	2.98	55.00	66.23
M_1	2.48	2.95	55.15	65.61
M_2	2.55	3.09	56.56	68.57
M_3	2.72	3.31	60.44	73.65
SEm±	0.02	0.02	0.48	0.41
LSD at 5 %	0.06	0.06	1.39	1.17
Interaction A × B				
SEm±	0.05	0.05	1.08	0.91
LSD at 5 %	0.13	0.14	3.11	2.61

Note: F_0 – Control (without fertilizer), F_1- 100% RDF as traditional fertilizer, F_2- 5ml each of Nano-NPK/ lit. of water as FA, F_3- 4ml each of Nano-NPK/ lit. of water as FA, F_4- 3ml each of Nano-NPK/ lit. of water as FA, M_0- control (without micronutrient), M_1- 2ml of nano-mix micronutrient/ lit. of water as FA, M_2- 4ml of nano-mix micronutrient/ lit. of water as FA, M_3- 6ml of nano-mix micronutrient / lit. of water as FA

Table 3b. Interaction effect of nano-fertilizer and nano-mixed micronutrient on fruit weight per plant and yield of tomato

Treatment combinations	Fruit weight (kg/ plant)		Fruit yield/ha (t)	
	2021	2022	2021	2022
F_0M_0	1.65	2.06	36.68	45.89
F_1M_0	1.75	2.15	38.92	47.80
F_2M_0	2.31	2.84	51.41	63.03
F_3M_0	2.23	2.72	49.54	60.43
F_4M_0	1.87	2.36	41.63	52.33
F_0M_1	1.83	2.26	40.62	50.11
F_0M_2	2.03	2.52	45.13	56.06
F_0M_3	2.12	2.62	47.20	58.17
F_1M_1	1.97	2.44	43.82	54.30
F_1M_2	2.40	2.93	53.42	65.00
F_1M_3	2.52	3.03	56.02	67.37
F_2M_1	2.91	3.59	64.62	79.75
F_2M_2	3.62	4.09	80.36	90.85
F_2M_3	3.80	4.23	84.43	93.94
F_3M_1	2.81	3.35	62.52	74.46
F_3M_2	3.22	3.89	71.57	86.48
F_3M_3	3.26	3.95	72.52	87.79
F_4M_1	2.63	3.20	58.34	71.19
F_4M_2	3.05	3.69	67.73	81.96
F_4M_3	3.12	3.75	69.26	83.43
SEm±	0.05	0.05	1.08	0.91
LSD at 5 %	0.13	0.14	3.11	2.61

The fruit size was increased by the application of nano-NPK and nano micronutrients because these nutrients increase the vigour of plants and assimilating the area and size of fruit, thereby resulting in a higher weight of fruit. However, this increasing trend in yield attributes with foliar application of NPK and nano micronutrients fertilization can be attributed to the physiological and metabolic roles of nutrients in flowering and enhances the supply of carbohydrates, which is necessary for effective pollination and fertility. Similar findings were observed by Rahman et al. (2021) and Roushan and Singh (2023) in tomato.

The cost of cultivation, net income, and benefit-cost ratio (B: C ratio) were also analyzed (Fig. 1). The F_2M_2 treatment combination proved to be the most economically beneficial, providing the highest net income (₹ 888,788.50 ha^{-1}) and the highest B: C ratio (6.42). This was followed by F_2M_3, with a B: C ratio of 6.10. The control treatment (F0M0) yielded the lowest net income (₹294,160.00 ha^{-1}) and B: C ratio (2.67),

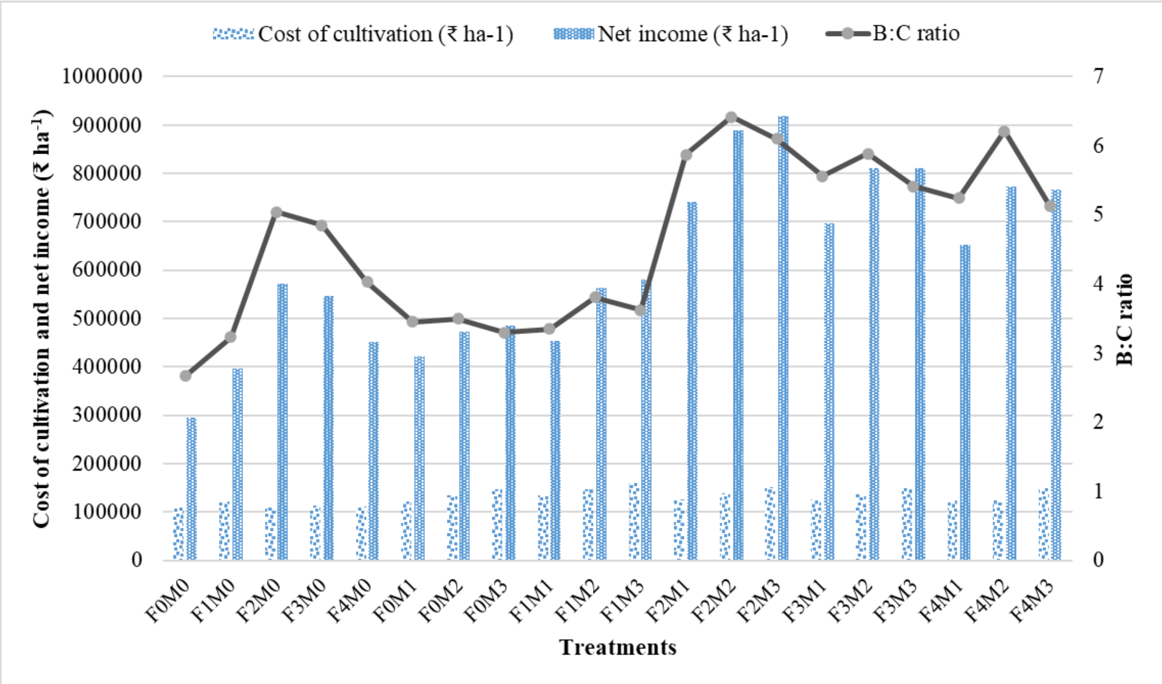

Fig. 1. Effect of nano-fertilizer and nano-mixed micronutrient on economic attributes of tomato (Based on pooled data of the years 2021 and 2022)

reinforcing the advantage of nano fertilizers and micronutrients for profitability. The treatments F_3M_2 and F_4M_2 also showed promising economic returns, further supporting the conclusion that nano-fertilizer technology can enhance both yield and economic viability in tomato cultivation.

4. CONCLUSION

The study demonstrated the significant positive impact of nano-fertilizers and nano-mixed micronutrients on the fruit set, fruit weight, total yield and economic profitability of tomato cultivation. The application of nano-NPK (F_3 - 4ml each of Nano-NPK/ lit. of water as FA and F_4- 3ml each of Nano-NPK/ lit. of water as FA) and nano-mixed micronutrients (M_3- 6ml of nano-mix micronutrient / lit. of water as FA) maximized the agronomic and economic returns. The interaction of F_2M_3 was found to be the most effective treatment for increasing yield and profitability, making it a recommended practice for tomato growers seeking to optimize both productivity and income.

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 writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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