Madras Agric.J.,2026; https://doi.org/10.29321/MAJ.261360

RESEARCH ARTICLE

Optimizing Fertigation Techniques for Enhanced Growth, Yield and Quality of Cherry Tomatoes (*Solanum lycopersicum* L. var. *cerasiforme*) in Protected Environments

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Received: 29 Jan 2026

Revised: 15 Apr 2026

Accepted: 26 May 2026

ABSTRACT

Cherry tomato (*Solanum lycopersicum* L. var. *cerasiforme*) is a high-value vegetable crop widely appreciated for its attractive colour, flavour, nutritional quality and antioxidant content. The present study was undertaken to evaluate the influence of different fertigation schedules using water-soluble fertilizers on the growth, yield and quality of cherry tomato cultivated under protected conditions. The experiment was conducted at the Protected Structure Orchard, Department of Vegetable Science, Horticulture College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, using the variety Pusa Cherry Tomato-1. Nine treatments comprising different combinations of soil application and fertigation with water-soluble fertilizers were evaluated in a Completely Randomized Block Design with three replications. Among the treatments, T_3 (100% RDF through fertigation using water-soluble fertilizers) recorded superior performance with respect to plant height, flowering characters, fruit set percentage, yield and quality parameters. The treatment produced the highest yield per hectare (23.95 t ha^{-1}), maximum lycopene content (8.16 mg 100 g^{-1}), total carotenoids (11.45 mg 100 g^{-1}) and total soluble solids (6.01 °Brix). The findings confirmed that precision fertigation through water-soluble fertilizers significantly improved nutrient use efficiency, fruit quality and productivity of cherry tomato under protected cultivation. The study also demonstrated the importance of evaluating reduced fertigation levels and integrated nutrient delivery systems for sustainable protected vegetable production.

Keywords: *Cherry tomato; Protected structure; Water-soluble fertilizers; Fertigation; Yield.*

INTRODUCTION

Cherry tomato (*Solanum lycopersicum* L. var. *cerasiforme*) has emerged as one of the most popular vegetable crops among consumers due to its attractive appearance, pleasant flavour and nutritional richness. The fruits are extensively used in salads, garnishes, processed products and fresh consumption owing to their sweetness and appealing colour. Cherry tomato fruits are rich sources of antioxidants such as lycopene, carotenoids, phenolic compounds, flavonoids, vitamin C and vitamin E, which contribute significantly to human health by reducing oxidative stress and preventing chronic diseases Retain Malik *et al.,* (2017); Yasuor *et al.,* (2020). Protected cultivation has become increasingly important in

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modern horticulture for achieving higher productivity, improved fruit quality and efficient resource utilization. Cultivation of cherry tomato under protected structures offers advantages such as regulation of temperature and humidity, reduced pest and disease incidence and better nutrient management. Among various modern nutrient management techniques, fertigation has gained considerable importance due to its precision and efficiency in nutrient delivery.

Fertigation represents an advanced agricultural technique wherein fertilizers are dissolved in irrigation water and applied directly to the root zone through drip irrigation systems (Hagin and Lowengart, 1995; Stoleru *et al.,* (2020)). This method improves nutrient availability and uptake efficiency while minimizing nutrient losses through leaching and volatilization. Fertigation using water-soluble fertilizers (WSF) has been reported to enhance nutrient recovery efficiency beyond 90%, compared to conventional fertilizer application methods which often exhibit lower efficiency (Kumar *et al.,* 2021; Wang *et al.,* (2024)). Water-soluble fertilizers are highly suitable for protected cultivation because of their rapid dissolution and immediate availability to plants. These fertilizers ensure precise nutrient application and improve growth, flowering, fruit development and quality attributes in vegetable crops (Sing *et al.,* 2022). Recent studies have also demonstrated that proper fertigation scheduling significantly enhances antioxidant activity, lycopene accumulation and overall fruit quality in tomato crops cultivated under greenhouse conditions Zhu *et al.*, (2023); Yasuor *et al.,* (2020). Although fertigation with water-soluble fertilizers has been widely adopted in commercial tomato cultivation, limited information is available regarding optimized fertigation schedules specifically for cherry tomato cultivation under protected environments. Cherry tomato differs from conventional tomato in nutrient demand, growth habit, fruit load and biochemical quality characteristics. Furthermore, comparative evaluation of reduced fertigation levels and integrated soil-fertilizer plus fertigation approaches under protected cultivation remains inadequately explored (Sun *et al., (*2024); Hu *et al.,* (2021)). Therefore, the present investigation was undertaken to standardize suitable fertigation schedules using water-soluble fertilizers for enhancing growth, yield and quality of cherry tomato under protected cultivation conditions.

MATERIALS AND METHODS

The experiment was conducted at the Protected Structure Orchard of the Department of Vegetable Science, Horticulture College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. The experimental material consisted of the cherry tomato variety Pusa Cherry Tomato-1. Seedlings were raised under protected conditions and transplanted at the age of 4–5 weeks during the four-leaf stage. The crop was planted at a spacing of 60 × 60 cm inside the protected structure. Recommended agronomic practices including staking, irrigation, intercultural operations and plant protection measures, were uniformly followed throughout the crop growth period. The experiment was laid out in a Completely Randomized Block Design (CRBD) with nine treatments and three replications. The treatment

Table 1. Fertigation treatment combinations imposed on cherry tomato

Treatments	Treatment details
T_1	Control – without fertilizer application and only irrigation
T_2	Soil application with straight fertilizer at 100% RDF
T_3	Fertigation with water-soluble fertilizers at 100% RDF
T_4	Fertigation with water-soluble fertilizers at 75% RDF
T_5	Fertigation with water-soluble fertilizers at 50% RDF
T_6	Fertigation with water-soluble fertilizers at 25% RDF
T_7	Soil application with straight fertilizer at 25% + Fertigation with water-soluble fertilizers at 75% RDF
T_8	Soil application with straight fertilizer at 50% + Fertigation with water-soluble fertilizers at 50% RDF
T_9	Soil application with straight fertilizer at 75% + Fertigation with water-soluble fertilizers at 25% RDF

combinations included different levels of fertigation using water-soluble fertilizers and combinations of soil-applied fertilizers with fertigation.

The reduced fertigation treatments involving 75%, 50% and 25% RDF through water-soluble fertilizers were included to evaluate nutrient use efficiency, fertilizer optimization and economic feasibility under protected cultivation conditions. Similarly, integrated combinations of soil-applied fertilizers and fertigation treatments were evaluated to compare the effectiveness of conventional and precision nutrient delivery systems (Singh *et al.,* 2022). Observations were recorded on growth parameters, including plant height at flowering, plant height at final harvest, days to first flowering, number of flowers per cluster, number of flowering clusters, number of fruits per cluster, number of fruit clusters per plant, days from fruit set to maturity and fruit set percentage. Yield and fruit parameters such as number of fruits per plant, fruit length, fruit girth, fruit width, number of locules per fruit, fruit weight, yield per plant and yield per hectare were recorded. Biochemical quality parameters including total soluble solids, total sugars, ascorbic acid, titratable acidity, lycopene, carotenoids, phenols and antioxidant activity, were also estimated using standard analytical procedures. Five randomly selected plants from each replication were utilized for recording observations and the mean values were subjected to statistical analysis.

RESULTS AND DISCUSSION

Effect of different fertigation treatments on growth parameters of cherry tomato

Significant variations among fertigation treatments clearly indicated the influence of nutrient delivery methods on vegetative growth and reproductive behaviour of cherry tomato under protected cultivation. The superior performance of fertigation treatments compared to conventional soil application may be attributed to continuous and uniform nutrient availability near the active root zone, thereby improving nutrient absorption efficiency and physiological activity of plants. The enhanced plant height observed under T_3 could be associated with improved nitrogen availability through drip fertigation, which promotes cell elongation, chlorophyll synthesis and photosynthetic activity. Fertigation also maintains optimum soil moisture and nutrient balance throughout crop growth, resulting in vigorous vegetative growth and better canopy development. Similar findings were reported by Singh *et al.,* (2023), who observed significant improvement in tomato plant growth under precision fertigation systems.

Earlier flowering observed under T_3 indicates that optimum nutrient supply accelerated the transition from vegetative to reproductive phase. Adequate phosphorus and potassium availability under fertigation may have enhanced floral initiation and reduced the duration required for flowering. Similar observations were made by Sallam *et al.,* (2021) in greenhouse tomato cultivation. The increased number of flowers and fruit clusters under T_3 could be attributed to improved assimilate production and enhanced source–sink relationship under protected conditions. Fertigation improves nutrient use efficiency and facilitates balanced uptake of essential nutrients, thereby increasing photosynthetic efficiency and reproductive growth. Stoleru *et al*., (2020) also reported that optimized fertigation management significantly improves flowering and fruiting behaviour in protected vegetable crops. The higher fruit set percentage under fertigation treatments may be due to reduced flower drop, enhanced pollen viability and improved nutrient availability during critical reproductive stages. Adequate potassium supply through fertigation is known to improve carbohydrate translocation and reproductive success in tomato crops. Overall, the results demonstrated that fertigation using water-soluble fertilizers positively influenced vegetative growth, flowering and reproductive parameters of cherry tomato under protected cultivation.

Effect of different fertigation treatments on growth parameters of cherry tomato

Significant differences were observed among the treatments with respect to growth parameters of cherry tomato under protected conditions. Treatment T_3 (100% RDF through fertigation using water-soluble fertilizers) recorded the maximum plant height at flowering (115.53 cm), followed by T_4 (112.71 cm), whereas the minimum plant height was observed in T_1 (86.70 cm). Similarly, the highest plant height at final harvest was recorded in T_3 (263.95 cm), followed by T_4 (261.57 cm). The increase in plant height under fertigation treatments could be attributed to efficient nutrient availability and enhanced nutrient uptake through drip fertigation systems, which promoted vigorous vegetative growth and root development (Singh *et al.,* (2023); Kumar *et al., (*2021)). The minimum number of days to first flowering was observed in T_3 (26.41 days), followed by T_4 (28.50 days), while the maximum duration was observed in T_1 (35.68 days).

Earlier flowering under fertigation treatments may be due to the timely availability of nutrients, especially nitrogen and potassium, which enhanced physiological activities and accelerated reproductive development. Similar findings were reported by Nair *et al.,* (2023). The maximum number of flowers per cluster (51.64), flowering clusters per plant (40.94), fruits per cluster (17.33) and fruit clusters per plant (19.73) were recorded in T_3. Enhanced flowering and fruiting characters under fertigation treatments may be attributed to increased photosynthetic efficiency, balanced nutrient availability and improved nutrient uptake efficiency under protected conditions Stoleru *et al.,* (2020). Fruit set percentage was also significantly influenced by fertigation treatments. The highest fruit set percentage was observed in T_3 (34.72%), followed by T_4 (33.89%), whereas the lowest value was recorded in T_1 (21.62%). The improvement in fruit set under fertigation treatments could be due to balanced nutrient supply and better physiological performance of plants under protected cultivation.

Effect of different fertigation treatments on fruit and yield parameters of cherry tomato

The significant improvement in fruit and yield parameters under fertigation treatments clearly demonstrated the effectiveness of precision nutrient management in protected cultivation systems. Yield improvement in cherry tomato is primarily associated with increased fruit set, enhanced fruit size and higher fruit weight, all of which were positively influenced by fertigation with water-soluble fertilizers. The increased number of fruits per plant under T_3 may be attributed to better nutrient availability throughout the crop growth period, resulting in improved flower retention and reduced fruit drop. Continuous nutrient supply through fertigation ensures optimum plant nutrition during flowering and fruit development stages, thereby increasing the sink strength of developing fruits. Fruit size parameters, including fruit length, girth and width were significantly higher under T_3, which may be due to improved cell division, cell enlargement and assimilate translocation under adequate nutrient supply. Nitrogen plays an important role in vegetative growth and chlorophyll synthesis, while potassium enhances carbohydrate transport and fruit development. Similar results were reported by Li *et al.*, (2021) and Sharma (2020), who observed increased fruit size and marketable yield in greenhouse tomato through drip fertigation. The higher fruit weight recorded under T_3 may be associated with improved photosynthetic activity and efficient nutrient absorption under fertigation conditions. Fertigation also reduces nutrient losses and maintains nutrient availability during critical crop growth stages, thereby improving fruit development and yield attributes. The substantial increase in yield per plant and yield per hectare under T_3 confirmed the superiority of fertigation over conventional fertilizer application methods. Enhanced nutrient use efficiency, better moisture regulation and balanced nutrient supply under protected cultivation may have collectively contributed to increased productivity. Similar findings were also reported by Wang *et al., (*2024) and Singh *et al.*, (2023).

The comparatively lower performance observed under reduced fertigation levels (T5 and T6) indicated that insufficient nutrient availability adversely affected growth and fruit development. However, the integrated nutrient treatments (T_7 and T_8) also recorded satisfactory performance, suggesting the possibility of partial substitution of conventional fertilizers with fertigation for improving fertilizer use efficiency. Overall, the results confirmed that fertigation with 100% RDF through water-soluble fertilizers is highly effective for improving fruit yield and productivity of cherry tomato under protected cultivation conditions.

Effect of different fertigation treatments on fruit and yield parameters of cherry tomato

The fertigation treatments significantly influenced fruit characters and yield attributes of cherry tomato. Treatment T_3 recorded the highest number of fruits per plant (326.50), fruit length (2.97 cm), fruit girth (5.14 cm), fruit width (0.98 cm), number of locules per fruit (2.02) and fruit weight (3.73 g). In contrast, the lowest values were observed in the control treatment (T_1). Improved fruit size and fruit weight under fertigation treatments may be due to enhanced nutrient uptake, increased metabolic activity and improved assimilate translocation towards developing fruits (Sing *et al.,* 2022).

The highest yield per plant (1211.38 g) and yield per hectare (23.95 t ha^{-1}) were recorded in T_3, followed by T_4 with 1183.50 g per plant and 23.67 t ha^{-1}, respectively. The increase in yield under fertigation treatments was mainly associated with improved flowering, higher fruit set percentage and increased fruit weight. Similar results were reported by Kumar *et al.* (2021), Singh et al., (2023) and Nair et al., (2023), who observed significant yield improvement in greenhouse tomato through precision fertigation. The findings clearly indicated that fertigation with 100% RDF through water-soluble fertilizers significantly enhanced productivity compared to conventional soil application methods.

Effect of different fertigation treatments on biochemical properties of cherry tomato

Biochemical quality parameters play a major role in determining the nutritional and market value of cherry tomato fruits. The present study revealed that fertigation treatments significantly improved biochemical constituents such as total soluble solids, ascorbic acid, lycopene, carotenoids, phenols and antioxidant activity. The increase in total soluble solids and total sugars under T_3 may be attributed to enhanced carbohydrate synthesis and accumulation resulting from improved photosynthetic activity under optimum nutrient availability. Potassium supplied through fertigation is known to facilitate sugar translocation and improve fruit quality characteristics. Higher ascorbic acid content under fertigation treatments could be due to increased metabolic activity and enhanced synthesis of vitamins under balanced nutrient conditions. Adequate nitrogen and potassium availability through fertigation improves enzymatic activity and stimulates biosynthesis of ascorbic acid in tomato fruits. Similar observations were reported by Yasuor *et al.,* (2020). The significant increase in lycopene and carotenoid content observed under T_3 indicated that fertigation positively influenced pigment synthesis and antioxidant accumulation in cherry tomato fruits. Lycopene is an important antioxidant compound responsible for the red colour and nutritional quality of tomato fruits. Improved nutrient uptake under fertigation may have enhanced biosynthetic pathways associated with carotenoid formation. The increased total phenol content and antioxidant activity observed under fertigation treatments may be due to enhanced synthesis of secondary metabolites under optimum nutrient management. Protected cultivation combined with precision fertigation creates favourable environmental conditions that improve fruit quality and antioxidant potential. Similar findings were reported by Sun *et al.*, (2024) and Kuzin *et al.,* (2021). The comparatively lower biochemical quality observed under reduced fertigation treatments could be attributed to inadequate nutrient availability and reduced metabolic activity. This highlights the importance of balanced nutrient supply for improving nutritional quality and functional attributes of cherry tomato fruits. Overall, the results

Table 2. Impact of Diverse Fertigation Treatments on Growth of Cherry Tomato

Treatment	Plant height at flowering (cm)	Plant height at final harvest (cm)	Days to first flowering	No. of flower cluster^{-1}	No. of flowering clusters	No. of fruit cluster^{-1}	No. of fruit clusters plant^{-1}	Days from fruit set to fruit maturity	Percent fruit set (%)
T_1	86.70	243.70	35.68	38.03	25.46	8.24	8.58	32.64	21.62
T_2	109.52	257.62	29.89	50.09	38.49	17.20	19.39	25.67	31.57
T_3	115.53	263.95	26.41	51.64	40.94	17.33	19.73	21.16	34.72
T_4	112.71	261.57	28.50	51.04	40.68	17.29	19.62	23.63	33.89
T_5	100.86	248.03	34.68	43.17	35.87	11.41	12.41	32.04	25.81
T_6	90.29	246.01	35.35	41.72	31.40	8.31	9.36	32.44	24.62
T_7	107.95	256.82	31.31	49.37	37.15	15.27	18.20	26.04	30.10
T_8	106.37	253.95	32.59	48.83	36.27	15.23	17.05	28.57	29.17
T_9	102.68	252.48	34.47	46.10	36.16	13.59	15.27	30.69	27.81
SE(d)	1.549	5.040	0.672	0.866	0.948	0.224	0.323	0.642	0.483
CD	3.280	10.669	1.424	1.834	2.007	0.474	0.683	1.360	1.023

Table 3: Impact of Diverse Fertigation Treatments on Cherry Tomato's Fruit Characters &Yield

Treatment	No. of fruit plant^{-1}	Fruit length (cm)	Fruit girth (cm)	Fruit width (cm)	No. of locules fruit^{-1}	Fruit weight(g)	Yield plant^{-1} (g)	Yield hectare^{-1} (tonnes)
T_1	214.70	2.75	3.53	0.72	1.90	3.28	697.92	13.96
T_2	323.72	2.91	4.97	0.93	1.97	3.66	1148.01	22.96
T_3	326.50	2.97	5.14	0.98	2.02	3.73	1211.38	23.95
T_4	325.38	2.95	5.06	0.94	2.00	3.70	1183.50	23.67
T_5	318.17	2.84	3.77	0.78	1.93	3.40	929.97	18.54
T_6	316.77	2.79	3.76	0.74	1.91	3.37	723.90	14.48
T_7	323.66	2.88	4.40	0.86	1.96	3.54	1077.61	21.55
T_8	319.64	2.88	4.02	0.83	1.95	3.47	1054.03	21.08
T_9	319.28	2.86	3.80	0.79	1.94	3.46	945.36	18.91
SE(d)	5.855	0.055	0.084	0.012	0.038	0.087	23.810	0.905
CD	12.396	0.116	0.178	0.025	N/A	0.185	50.410	0.427

Table 4: Effect of Different Fertigation Treatments on the Biochemical Properties of Cherry Tomatoes

Treatment	TSS (°Brix)	Total Sugar (mg 100 g^{-1})	Ascorbic acid (mg 100 g^{-1})	Titrable acidity (%)	Lycopene (mg 100 g^{-1})	Total carotenoid (mg 100 g^{-1})	Total phenol (mg 100 g^{-1})	Total antioxidant (μ mol. AA g^{-1})
T_1	4.72	1.85	21.09	0.11	7.29	10.31	0.32	1.03
T_2	5.66	2.00	25.93	0.93	7.98	11.18	0.49	1.15
T_3	6.01	2.04	27.87	0.96	8.16	11.45	0.51	1.18
T_4	5.81	2.02	27.18	0.94	8.06	11.22	0.50	1.16
T_5	4.93	1.88	22.96	0.14	7.42	10.65	0.38	1.06
T_6	4.82	1.87	21.11	0.13	7.37	10.54	0.35	1.04
T_7	5.28	1.97	25.17	0.85	7.83	11.10	0.47	1.14
T_8	5.08	1.96	24.66	0.82	7.76	11.05	0.44	1.11
T_9	4.94	1.94	23.67	0.81	7.47	10.87	0.43	1.09
SE(d)	0.096	0.031	0.420	0.019	0.174	0.268	0.010	0.021
CD	0.203	0.066	0.890	0.040	0.369	0.567	0.022	0.044

demonstrated that fertigation using water-soluble fertilizers not only enhanced productivity but also significantly improved the nutritional and biochemical quality of cherry tomato fruits under protected cultivation.

Effect of different fertigation treatments on biochemical properties of cherry tomato

Different fertigation treatments significantly influenced biochemical quality parameters. Treatment T_3 recorded the highest total soluble solids (6.01 °Brix), total sugar content (2.04 mg 100 g^{-1}), ascorbic acid content (27.87 mg 100 g^{-1}), titratable acidity (0.96%), lycopene content (8.16 mg 100 g^{-1}), total carotenoids (11.45 mg 100 g^{-1}), total phenols (0.51 mg 100 g^{-1}) and antioxidant activity (1.18 μ mol AA g^{-1}). The improvement in biochemical quality parameters under fertigation treatments may be attributed to enhanced nutrient uptake and improved

Fig.1. Effect of Fertigation on plant height

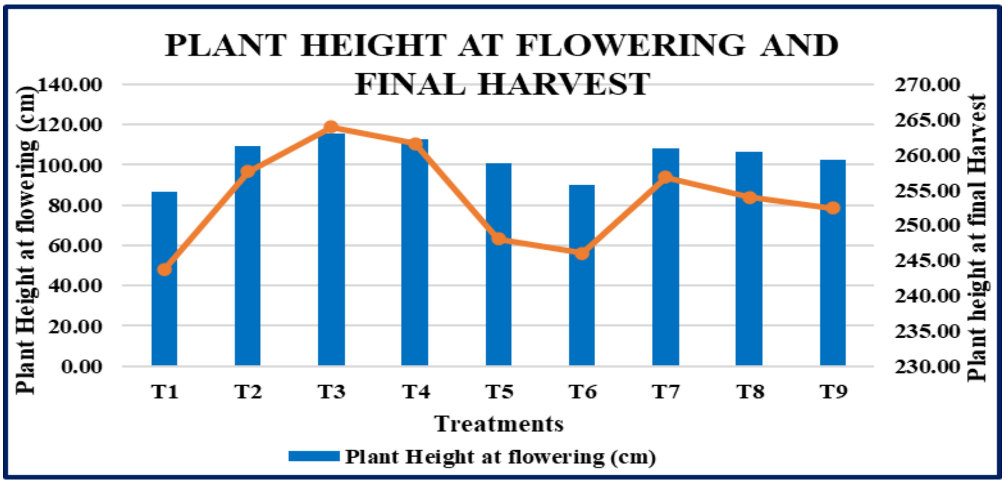


Fig.2. Effect of Fertigation on flowering characters

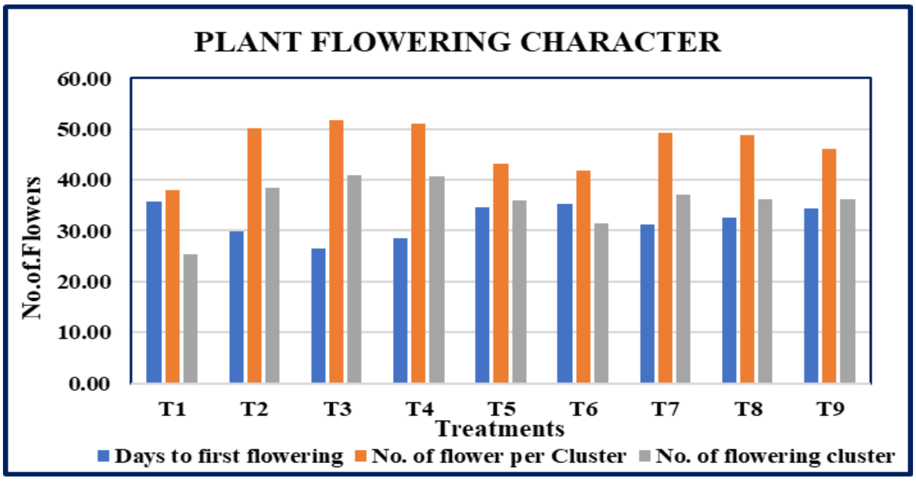


Fig. 3. Effect of Fertigation on fruit set percentage

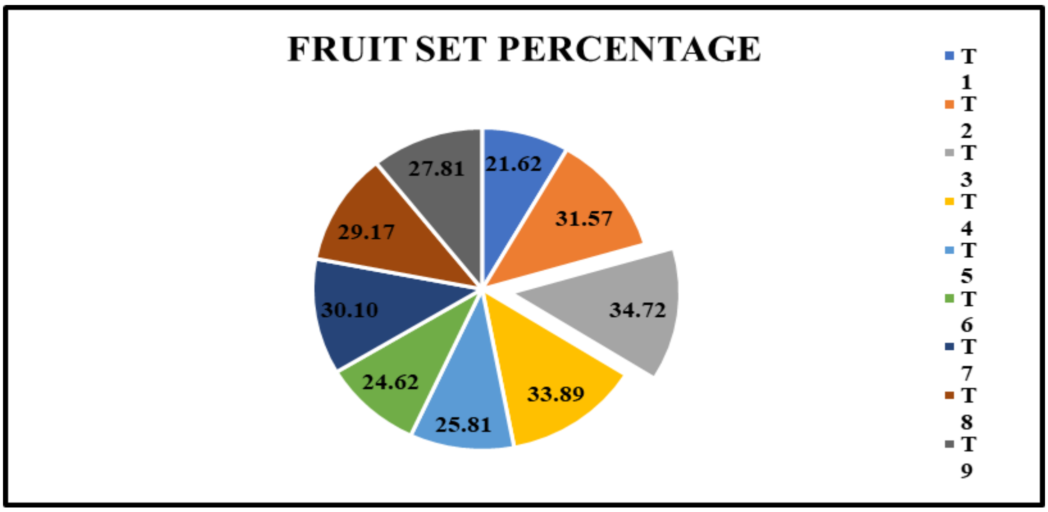


Fig.4 Effect of Fertigation on Yield per Plant and Hectare

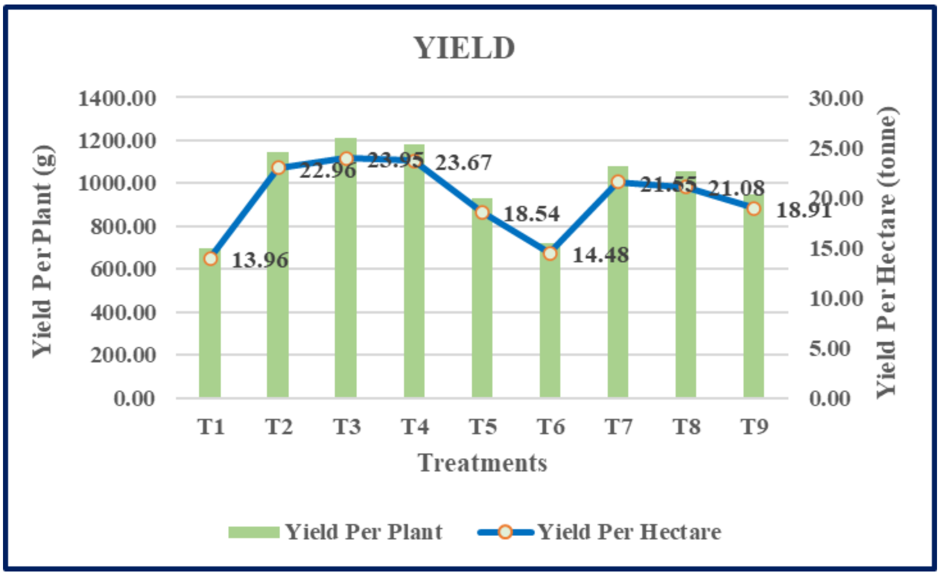
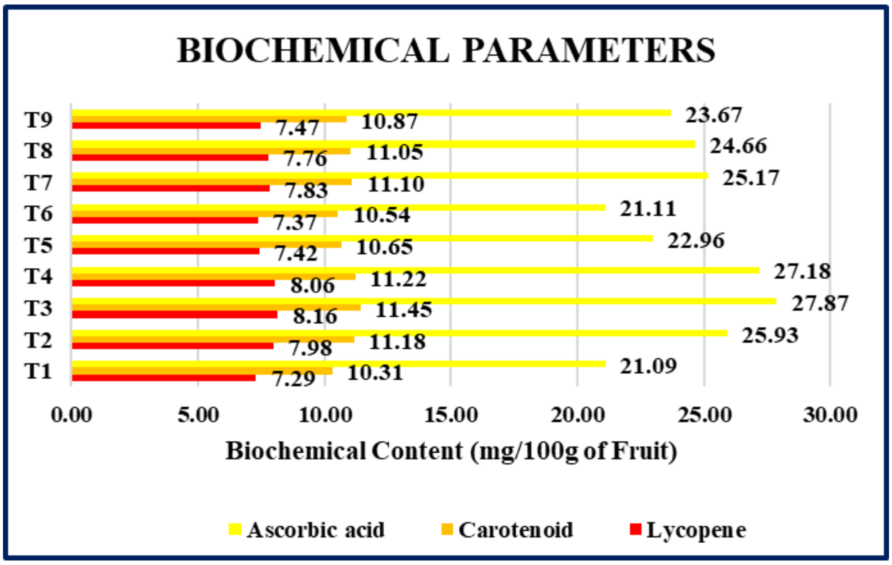


Fig. Effect of fertigation on biochemical characters



photosynthetic activity under protected cultivation conditions. Adequate availability of nitrogen and potassium through fertigation has been reported to improve sugar accumulation, vitamin C synthesis and antioxidant activity in tomato fruits Zhu *et al.,* (2023); Hernández *et al.,*(2022). Improved nutrient availability through fertigation significantly enhanced lycopene, carotenoid and antioxidant accumulation in cherry tomato fruits due to improved metabolic efficiency and increased biosynthesis of secondary metabolites under protected conditions Jain *et al.,* (2021); Li *et al.,* (2021). The results confirmed that fertigation not only improved yield but also enhanced the nutritional quality of cherry tomato fruits.

CONCLUSION

The present investigation established that fertigation using water-soluble fertilizers is an efficient and sustainable nutrient management strategy for cherry tomato cultivation under protected environments. Among the treatments evaluated, T_3 (100% RDF through fertigation using water-soluble fertilizers) recorded superior performance with respect to growth, flowering, fruit set, yield and biochemical quality parameters. The study also highlighted the importance of evaluating reduced fertigation levels and integrated nutrient delivery approaches for improving nutrient use efficiency and fertilizer optimization under protected cultivation systems. The findings demonstrated that precision fertigation significantly enhanced nutrient uptake efficiency, productivity and fruit quality compared to conventional fertilizer application methods. The broader adoption of fertigation techniques using water-soluble fertilizers can contribute substantially towards sustainable protected cultivation, improved resource management and enhanced profitability of high-value vegetable crops. Future studies may focus on crop-specific fertigation scheduling under different agro-climatic conditions and economic analysis of fertigation practices

Ethics Statement

This study did not involve human participants or animals. The research was conducted solely on plant materials; therefore, ethical approval was not required.

Originality and Plagiarism

The authors confirm that this manuscript is an original work and has not been published previously nor is it under consideration for publication elsewhere. All sources of information have been appropriately cited, and the manuscript is free from plagiarism.

Consent for Publication

All authors have read and approved the final version of the manuscript and consent to its publication in the journal.

Competing Interests

The authors declare that they have no competing financial or non-financial interests that could have influenced the work reported in this manuscript.

Data Availability

All data generated or analyzed during this study are included in this published article. Additional data related to this study are available from the corresponding author upon reasonable request.

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