



RESEARCH ARTICLE

Improvement in tomato productivity through a novel wireless based automated drip irrigation system design

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Received: 27 November 2025; Accepted: 13 May 2026; Available online: Version 1.0: 10 July 2026

Cite this article: Pandey SK, Pandey AK, Mishra PK, Kumar M, Yadav P, Kumar V, Singh AK. Improvement in tomato productivity through a novel wireless based automated drip irrigation system design. Plant Science Today. 2026; 13(sp5): 1-9. <https://doi.org/10.14719/pst.12967>

Abstract

The present study was conducted to design, develop and evaluate a wireless-based automated drip irrigation system for improving the productivity of tomato crop. Various independent and dependent parameters were considered in design of automated drip irrigation system. The field trial included soil analysis, experimental layout, evaluation of drip system and crop under different irrigation treatments. The highest yield was recorded in wireless irrigation system with treated fruit processing wastewater during both the years of study. In wireless irrigation system, crop irrigated with pressure compensating dripper (PC) has an average yield of 377.97 q ha⁻¹ which is higher as compared to non-pressure compensating dripper (NPC) (364.65 q ha⁻¹). Under the treatments involving the use of fruit processing wastewater in the tomato crop, the percentage of protein, moisture content, carbohydrates, lycopene and sugar increased as compared to those under groundwater irrigation. Treatments comprising of fruit processing wastewater recorded higher dry matter accumulation (6.67 %) and more amounts of lycopene (4.50 mg/100 g) as compared to ground water treated plots. The study revealed that the automated drip irrigation system is an efficient irrigation approach, as it reduces water, labour, energy, time and fertiliser use.

Keywords: automated drip irrigation system; non-pressure compensating dripper; pressure compensating dripper; tomato; water quality; wireless network

Introduction

Water availability has emerged as a critical constraint in sustaining agricultural productivity worldwide, particularly in regions reliant on irrigated farming. According to United Nations projections, by 2030 global freshwater demand is predicted to exceed supply by about 40 %, with India positioned as one of the most affected countries by water scarcity (1). In India, agriculture accounts for approximately 80 % of total water usage (2), placing immense pressure on groundwater resources and accelerating their depletion at unsustainable rates (3).

Efficient irrigation management is essential to optimise crop yield, especially in arid and semi-arid zones where water competition is intense and rainfall is insufficient to meet crop water requirements (4–5). Climate factors specific to a given crop phase influence both the quantity and timing of irrigation water demand as well as crop yield fluctuations. Effective irrigation scheduling determines when and how much to irrigate is vital for maximising water-use efficiency and economic returns (6–7).

Drip irrigation systems, particularly automated variants, offer promising solutions for precision water delivery. Traditional wired systems, however, are typically suited for large farms, require

frequent maintenance and suffer from limitations such as degradation of plastic components under harsh climatic conditions and complex installation procedures (8–10). These challenges hinder scalability and long-term sustainability.

Wireless-based automated drip irrigation systems present a viable alternative, offering site-specific control, reduced infrastructure costs and simplified installation. Wireless sensor networks (WSNs) enable fine-grained, real-time monitoring of soil and environmental parameters, enhancing irrigation precision and resource efficiency (11–13). The adoption of WSNs has demonstrated significant benefits, including reductions in water usage, energy consumption, labour and structural damage (14–17).

For optimal plantation management, accurate and timely data covering agronomic, soil, atmospheric and physicochemical parameters is indispensable (18). In this context, the development of an indigenous, low-cost wireless automated irrigation system tailored to crop-specific needs is both timely and necessary.

This study aims to design and evaluate a novel wireless-based automated drip irrigation system and assess its effectiveness in enhancing tomato productivity while promoting sustainable water use.

Materials and Methods

The wireless-based automated drip irrigation system was evaluated at experimental agricultural farm of Jain Irrigation System Limited in Jalgaon, Maharashtra, India, located at 21.0833°N (Latitude) and 75.6667°E (Longitude) and situated at an altitude of ~209 m above mean sea level. The irrigation system, described in the following sections, was designed considering several independent and dependent parameters (19).

Design of automated drip irrigation system

The design of wireless based automated drip irrigation system differs from crop to crop, plot to plot, soil to soil and climatic conditions. In general, the steps involved in designing the automated drip irrigation system are shown in Table 1. The design provides a comprehensive mathematical framework to estimate water requirements, design components (lateral, submain, main pipelines), calculate irrigation time and select appropriate pumping systems for efficient drip irrigation. Parameters such as crop evapotranspiration, system efficiency, dripper characteristics, pipe dimensions and energy losses are integrally considered (19).

Irrigation application and fertigation

Irrigation to the crop is done with the help of automated drip irrigation system. Water pumps (2.5 H.P.) with discharge capacity ranging between 5–13 m³ hr⁻¹ are fitted into a plastic tank in the experimental field. Filtration unit comprising of primary and secondary filters are used for filtering the ground water and the treated fruit processing wastewater for irrigation purposes. Fertigation is given to the crop with the help of fertjet monitoring machine (3050, AMEC0B01). A set of three venturiers, each having discharge capacity of 360 L hr⁻¹ (lph), are connected with the fertjet monitoring machine (19).

The system automatically shuts down if the required EC/pH values fall outside the predefined range.

For the wireless-based automated drip irrigation system five sensors are used namely, wind sensor (Capacity up to 50 m/s), digital temperature sensor (up to -10 °C to +85 °C capacity), humidity sensor, tensiometer for moisture sensing and rain sensor. The sensors are connected to data logger which records the information at desired time interval (Fig. 1).

Table 1. Mathematical formulas for cost calculation

Parameter	Formula
Peak water requirement	$\text{Peak water requirement} = \frac{\text{PET} \times \text{Crop factor} \times \text{Canopy factor}}{\text{Efficiency of the system}}$ Where: PET = potential evapotranspiration (mm/day)
Drippers selection and computation of irrigation time	
Water application rate	$\text{WAR} = \frac{\text{Dripper discharge}}{\text{Line to line spacing} \times \text{Dripper to drifter spacing}}$
Irrigation time	$\text{Irrigation time} = \frac{\text{Peak water requirement}}{\text{Water application rate}}$
No. of irrigation section possible according to time	$\text{Number of irrigation section} = \frac{\text{Electricity available}}{\text{Irrigation time}}$
No. of irrigation section possible according to flow	$\text{No. of irrigation sections} = \frac{\text{Daily flow required for total field (ND} \times \text{DD)/3600) lps}}{\text{Pump discharge (lps)}}$ Where: ND = Number of drippers DD = Dripper discharge
Design of lateral	$hf = 5.35 \left(\frac{Q^{1.852}}{D^{4.871}} \right) \times L$ Where: hf = total energy drop friction at the end of lateral Q = Total discharge at the end of lateral (lit/sec) D = Internal diameter of the pipe (m) L = Length in pipe (m) L = Hazen William constant (150 assumed for PVC, LLDPE)
Design of sub main pipeline	$\text{SDR of submain line} = \frac{\text{No. of drippers covered by submain} \times \text{Dripper discharge}}{\text{Length of submain}}$ Where: SDR = standard dimension ratio
Design of main pipeline	$\text{Mainline sectional flow (lps)} = \frac{\text{Number of dripper} \times \text{Dripper discharge}}{3600}$ Where: lps = litre per second
Selection of pump	Total head required = (suction head + delivery head) + head loss in filters + loss in mainline + operating pressure of system + head loss in venturiers + upward elevation if any

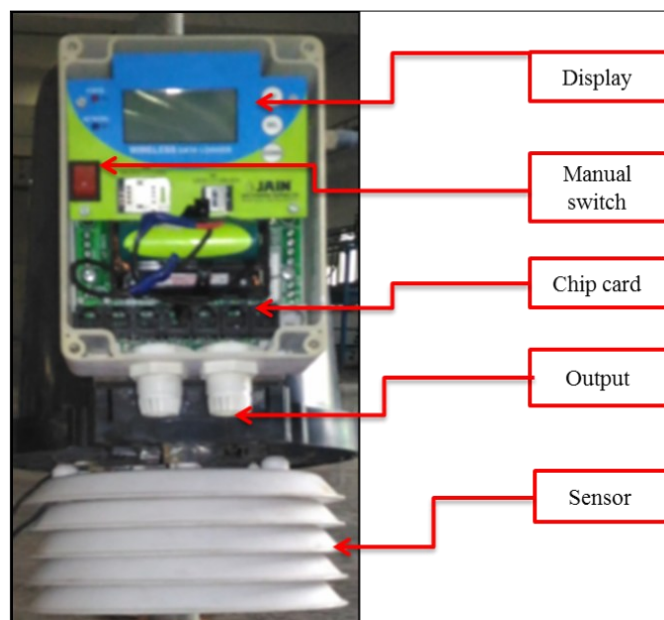


Fig. 1. Operational view of data logger.

For the development of wireless automated drip irrigation system, signal controller, SPV (solenoid pilot valve), T joint, elbow, mounting plate, end plug, hydraulic tube, hydraulic valve, mounting pole, universal serial bus (USB) on-the-go cable, battery, radio remote terminal unit (RTU) and antenna are used.

A software program is used for interfacing the code with the hardware chip. Base station communicates with all radio terminals at the same time. Time based scheduling is provided and the software works on event-based terminology. This software has been designed by using (.NET) language which manages the code for common language to run time. This software provides a framework to manage fertigation and irrigation through implemented microcontroller for irrigation purposes (19). A view of block diagram of wireless network system is shown in Fig. 2.

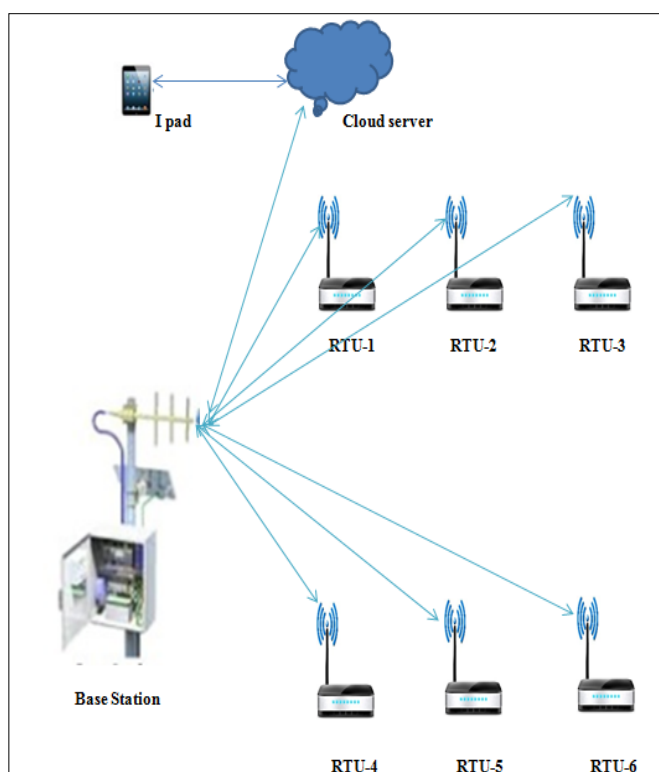


Fig. 2. A view of block diagram of wireless network system.

Evaluation of designed drip irrigation system

The field trial included soil analysis, experimental layout, evaluation of wireless based automated drip system and crop under different irrigation treatments as follows:

Soil testing

Based on soil analysis data the soils under study were found to be of clay loam texture with moderate field capacity and low bulk density. The pH of the soil was 6.5. All the soil nutrients viz., calcium (Ca), magnesium (Mg), phosphorous (P), nitrogen (N), potassium (K) and sulphur (S) and micronutrient manganese (Mn), zinc (Zn), iron (Fe) and copper (Cu) were found to be higher on the soil surface as compared soil samples collected from 10 cm depth. Potassium content was an exception with higher values in deeper soils. The amounts of silt and sand in the tested soils were found to be 32.3 % and 33.48 % respectively.

Agronomic practices

The agricultural field was ploughed and repeatedly tilled with the help of cultivator to bring optimum soil tilth. Ridges of 9 m length were prepared for transplanting of tomato plants. The variety of tomato used for this study was “Abhinav” which was procured from Syngenta and was transplanted at 250 g seedlings per ha of the agricultural field with a plant-to-plant spacing of 30 cm and plant rows at a spacing of 60 cm. During preparation of ridges farmyard manure was applied at 12 tonnes/acre.

The chemical fertiliser inputs as per the recommended doses of fertiliser (applied at 150 kg/ha N, 75 kg/ha P and 50 kg/ha K) utilised for tomato crop were given in the form of urea, diammonium phosphate (DAP) and muriate of potash (MOP). Total fertiliser amount was distributed into 20 splits, out of which 20 % was equally divided into 8 doses and remaining 80 % divided into 12 doses and the fertilisers were applied at 4-day intervals. Weeding operations were carried out manually at 30 days' intervals. The alternate spray of Indofil M-45 was done at 10 days' interval to protect plants from early blight diseases due to high humidity. In case of appearance of late blight symptoms, the affected plants were sprayed with Redomil spray followed by Indofil M-45 at weekly intervals, to protect the crop from late blight diseases. When the fruiting started, the fruits were protected from stem borer larva attack by spraying neem oil as per requirement.

Field experimental layout

The experiment was conducted on tomato crops at the experimental farm located near the Jain Irrigation Systems Limited (JISL) food processing facility in Jalgaon, Maharashtra, India. WQ₁ (ground water, GW) and WQ₂ (treated fruit processing wastewater, TFPWW), two distinct irrigation sources depending on water quality, were applied using non-pressure compensative and pressure compensative emitters, each with 5 replications. A total of 20 control valves for 20 sections (50 mm) were chosen for each of the 5 replications (R1, R2, R3, R4 and R5) in the 1000 m² experimental plot with 9 × 4 m plot dimensions.

Field crop parameters

The biometric parameters such as plant height, number of leaves and number of branches were measured at interval of 30, 60 and 90 days after transplanting. Five plants were selected from each plot randomly and tagged for identification. Plant height was measured from ground level of the plant to the tip of the topmost leaf using measuring scale. The numbers of branches and number of leaves

were counted for selected plants. Number of fruits were counted for the same plants upon fruiting initiation i.e. 45, 60 and 90 days after transplanting.

Yield parameters

The matured tomato fruits were harvested manually at 4-day intervals from whole plot. The total weight of fruits was recorded at each harvesting for each plot.

Quality parameters

For determination of nutritional quality parameters, five fruits harvested randomly from each plot were investigated in the laboratory. Samples were analysed in triplicate for protein, carbohydrates, fats, crude fibre and ash content using standard procedures (19).

Results and Discussion

During the study observations recorded at the progressive stages of the experiment were analysed statistically to assess the degree of variance due to treatments. The results of the experiments are presented in the following sections:

Biometric attributes

During the study, biometric attributes of the tomato crop i.e., plant height, number of leaves and number of branches were observed.

(a) Plant height

The maximum average plant height (88.5 cm) was recorded under PC dripper irrigation using treated fruit processing wastewater (WQ₂) at 90 days after transplanting (D3). The minimum average plant height (35.97 cm) was recorded under NPC dripper for ground water (WQ₁) at 30 days after transplanting (D1).

At a 95 % confidence interval, Fig. 3 shows that the dripper type, growth days and water quality have a substantial impact on plant height ($p < 0.0001$). Across all treatments, the mean plant height ranged between 35.97 and 88.5 cm and at the 5 % level of

significance, the difference was statistically significant ($p = 0.0001$). For water quality, dripper type and growing days, the corresponding critical differences (CD at 5 %) were 0.70, 0.70 and 0.85. At the 5 % level of significance, the combined effects of dripper type, growth days and water quality did not significantly affect tomato plant height. A study published a similar finding, showing that sandy clay loam soil had better uptake of N and K, indicating an increase in plant height (20).

(b) Number of leaves

Maximum number of leaves (18.6) was observed for PC dripper at 60 days (D2) under the treatment involving use of fruit processing wastewater (WQ₂). The minimum number of leaves were observed for ground water (WQ₁) with non-pressure compensating (NPC) dripper at 30 days after transplantation (9).

The data for number of leaves showed significant differences among water quality, dripper type and days. The combined effect of water quality, dripper type and days was not statistically significant on the number of leaves at 5 % level of significance.

The dripper type, growth days and water quality significantly affect the number of leaves ($p < 0.0001$) at 95 % confidence interval (Fig. 4).

The mean value of number of leaves varied from 9 to 18.6 among all the treatments and the difference was statistically significant ($p = 0.0001$) at 5 % level of significance. The CD at 5 % for water quality, dripper type and growth days was observed as 0.41, 0.41 and 0.51 respectively.

The reason for bearing of maximum number of leaves under treatment comprising of application of treated fruit processing wastewater with pressure compensative dripper can be attributed to the accurate and uniform irrigation and fertigation provided by pressure compensating drippers. Similar results were reported for tomato vegetative growth of crop under treated wastewater application (21).

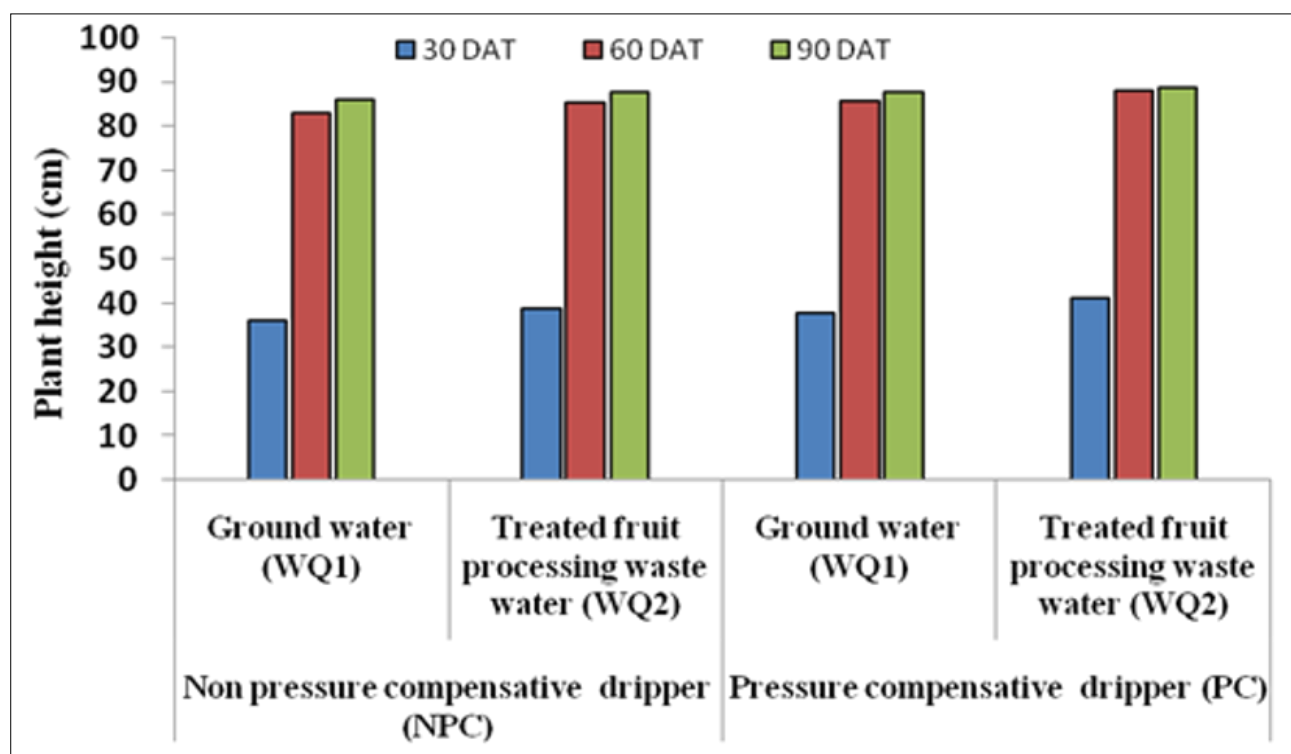


Fig. 3. Plant height of tomato crops under the applied treatments regimen.

DAT: days after transplanting.

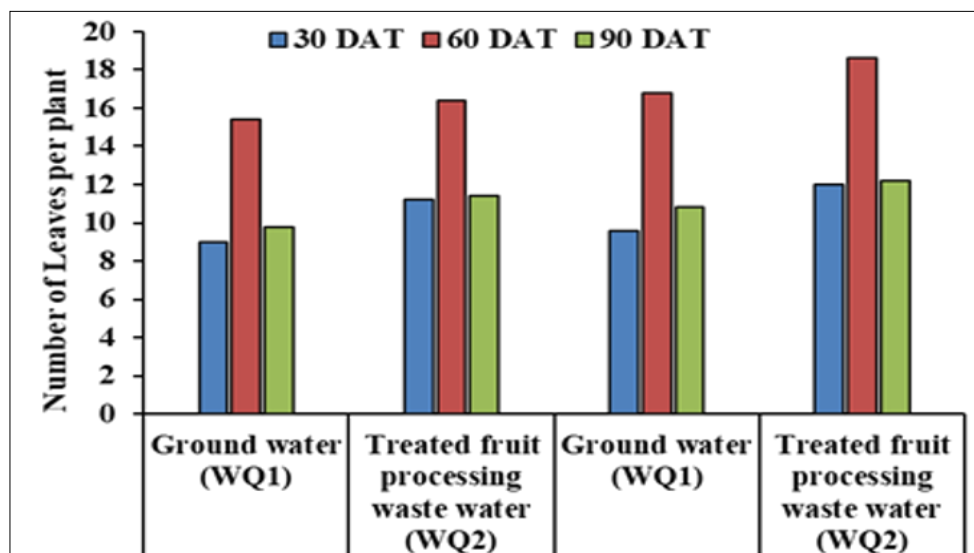


Fig. 4. Number of leaves in tomato crops under the applied treatments regimen.

DAT: days after transplanting.

(c) Number of branches

Maximum average number of branches (8.6) was observed for treatment involving use of PC dripper for applying treated fruit processing wastewater (WQ₂) at 90 days after transplanting (D3). The minimum branches (2.4) were observed for treatment in which ground water (WQ₁) was applied with NPC dripper at 30 days after transplanting. The mean value of number of branches varied from 3 to 8 in the interaction between days and dripper type and the difference was statistically significant ($p = 0.0001$) at 5 % level of significance. The CD at 5 % for the interaction between days and dripper type was observed to be 0.54.

The dripper type, growth days and irrigation water quality significantly affected the number of branches ($p < 0.0001$) at 95 % confidence interval (Fig. 5). The mean value of number of branches varied from 3 to 8 among all the treatments and the difference was statistically significant ($p = 0.0001$) at 5 % level of significance. The CD

at 5 % for irrigation water quality, dripper type and growth days were observed as 0.31, 0.31 and 0.38 respectively.

The combined effect of irrigation water quality dripper type and growth days was not statistically significant on the number of branches at 5 % level of significance. In pressure compensating dripper a greater number of branches has been found as compared to non-pressure compensating dripper, irrespective of days after transplanting (Fig. 6). Similar result was reported previously for tomato crop production (22).

Yield attributes

Yield attributes of the tomato crop were evaluated in terms of the number of fruits per plant and fruit yield (q ha^{-1}).

(a) Number of fruits

Maximum number of fruits (11.2) were observed at 60 days after transplanting under treatment involving application of treated fruit processing wastewater (WQ₂) through PC dripper. The minimum

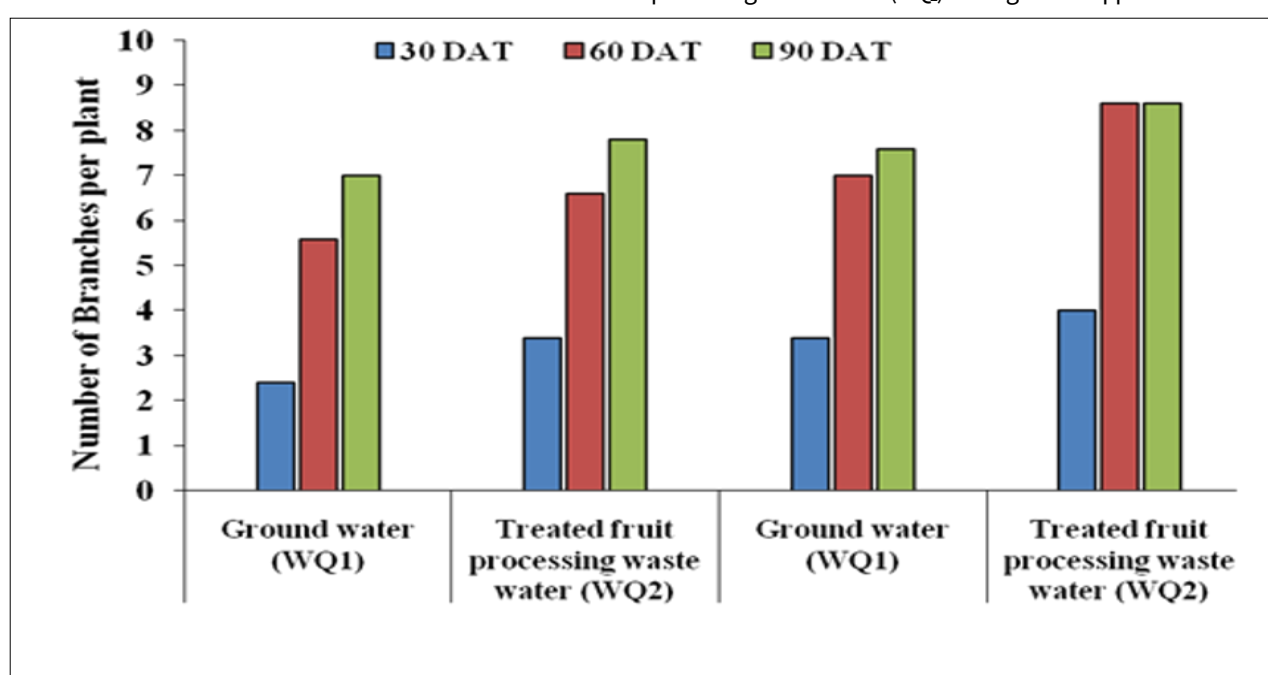


Fig. 5. Number of branches in tomato crop under the applied treatments regimen.

DAT: days after transplanting.

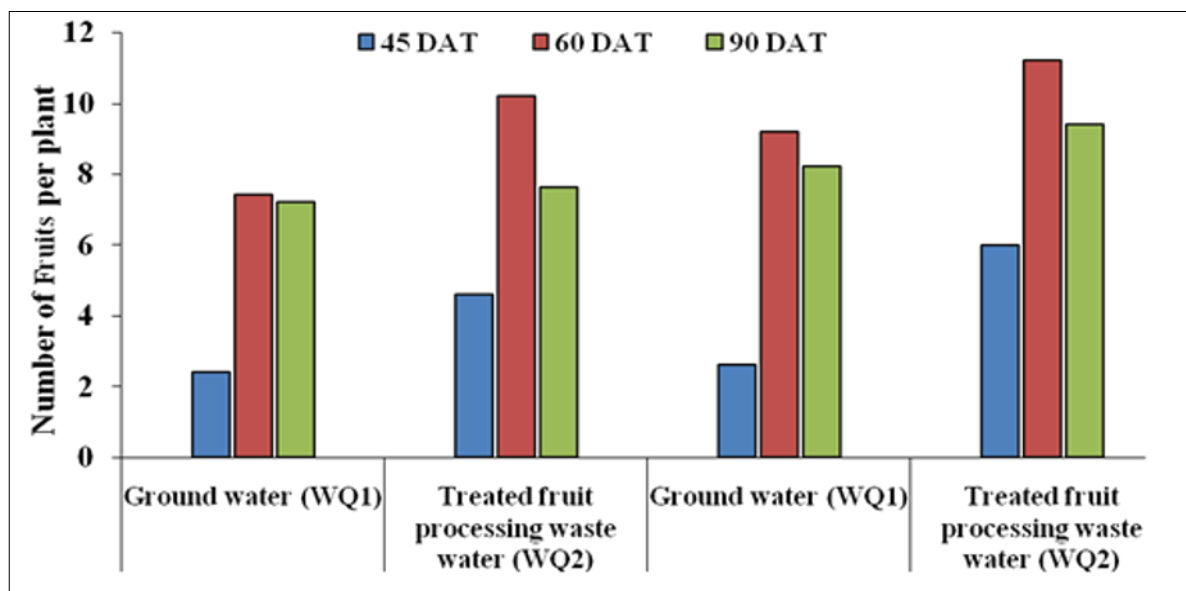


Fig. 6. Number of fruits per plant in tomato crops under the applied treatments regimen.

DAT: days after transplanting.

fruits (2.4) were borne in plants under treatment involving application of ground water (WQ₁) with non-pressure compensating (NPC) dripper at 45 days after transplanting. Similar results were reported for tomato crop production (22). The dripper type, growth days and irrigation water quality significantly affected the number of fruits ($p < 0.0001$) at 95 % confidence interval (Fig. 6). The number of fruits varied from 2.4 to 11.2 among all the treatments and the differences were statistically significant ($p = 0.0001$) at 5 % level of significance. The CD at 5 % for irrigation water quality, dripper type and growth days were observed as 0.3, 0.3 and 0.37 respectively. The combined effect of irrigation water quality, dripper type and growth days were not statistically significant for the number of fruits at 5 % level of significance.

(b) Crop yield

Both PC and NPC dripper as well as irrigation water quality significantly affected the tomato crop yield ($p < 0.0001$) at 95 % confidence interval (Fig. 7). The mean value of tomato yield as affected by the irrigation water quality varied from 350.4 q ha⁻¹ (WQ₁) to 371.1 q ha⁻¹ (WQ₂) whereas the difference in yield as affected by the type of utilised dripper (NPC / PC dripper) varied from 344.7–378 q ha⁻¹ among all the treatments and the difference was

statistically significant ($p = 0.0001$) at 5 % level of significance. The CD at 5 % for water quality was observed to be 4.63.

Maximum tomato yield was observed 377.97 q ha⁻¹ with PC dripper for treated fruit processing wastewater (WQ₂). The minimum was observed 344.67 q ha⁻¹ with NPC dripper for ground water (WQ₁). The reason of higher yield of tomato crop because treated fruit processing wastewater obtained, had more content of macro and micronutrients as compared to ground water which effects the vegetative growth and yield of the crop. Also, pressure compensating drippers do accurate and uniform irrigation and fertigation. Therefore, it was best suited for tomato crop.

Optimisation of independent attributes for irrigation system

The observation for temperature, relative humidity, evaporation, soil moisture and soil temperature in respect of irrigation system, were analysed. All the data collected from field experiment is shown in Appendix B and it was analysed in the SPSS software for the regression analysis to derive the standard equation in the form of $y = ax_1 + bx_2 + cx_3 + d$. The coefficients (a, b, c and d) were calculated from the software for both the systems and shown in Table 2 and 3. All the values of coefficient were placed in the standard equation which derived the

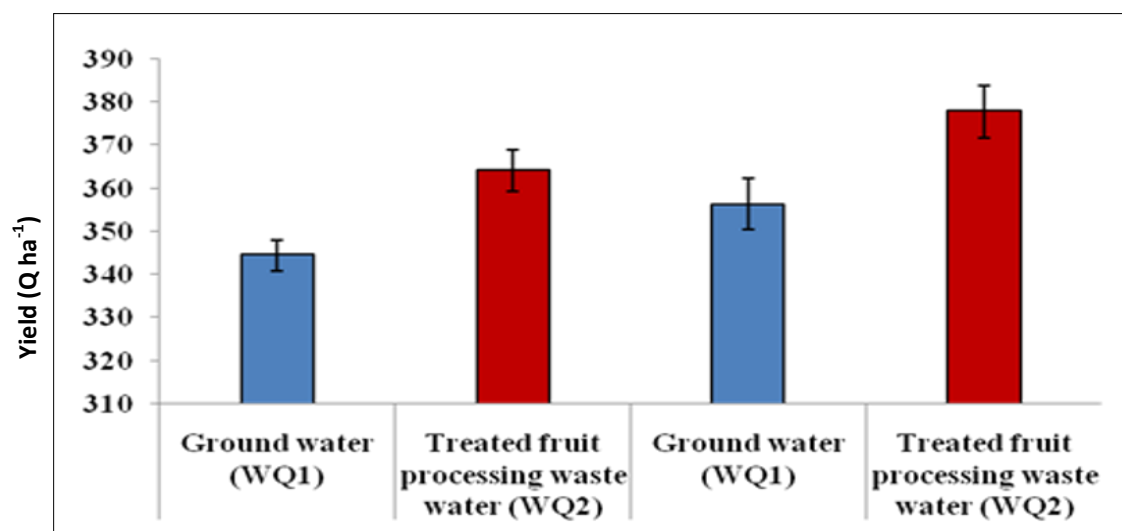


Fig. 7. Yield of tomato crop under the applied treatments regimen.

regression equations. From the result, it is revealed that all the independent attributes affect the temperature, relative humidity, evaporation, soil moisture and soil temperature for the irrigation system.

For the wired based irrigation system, the value of standard error for temperature, relative humidity, evaporation, soil moisture and soil temperature was calculated as 1.72, 1.91, 0.39, 0.94 and 1.90, respectively (Table 2). The value of R² for temperature, relative humidity, evaporation, soil moisture and soil temperature was calculated as 0.932, 0.963, 0.872, 0.655 and 0.820 respectively. It was observed that the temperature, relative humidity has strong relationship for wired based irrigation system.

For wireless based system, the value of standard error for temperature, relative humidity, evaporation, soil moisture and soil temperature was computed as 1.60, 1.91, 0.46, 0.95 and 1.32 respectively (Table 3). The value of R² for temperature, relative humidity, evaporation, soil moisture and soil temperature was calculated as 0.94, 0.963, 0.864, 0.677 and 0.872 respectively. It was observed that the temperature, relative humidity has strong relationship for wireless based irrigation system.

For wired based irrigation system, the average value of R² and standard error was 0.848 and 1.37 respectively. Similarly, for wireless based irrigation system, the average value of R² and standard error was 0.863 and 1.24 respectively. From these results, it is revealed that wireless based irrigation system has strong relationship and less standard error as compared to wired based irrigation system. Based on the regression analysis the best result was obtained in the wireless based irrigation system in comparison to wired based irrigation system.

Based on the environmental attributes the best system was identified. To economise overall system design, the indigenous control circuitry was implemented using various pressure levels and emitter discharges. To further verify the optimisation of the both the system was also carried out by considering biometric attributes.

Optimisation of independent attributes for irrigation system based on biometric attributes

Table 2. Mathematical relation of dependent and independent attributes for wired based system

Dependent attributes	Equations	R ²	p value	Standard error
Temperature (°C)	$T = 0.197X_1 - 0.246X_2 + 41.23$	0.932	0.002	1.72
Relative humidity (%)	$RH = -0.467 X_1 + 0.38 X_2 + 44.7$	0.963	0.001	1.91
Evaporation(mm)	$E = X_1 - 0.40X_2 + 6.044$	0.872	0.001	0.39
Soil moisture (%)	$SM = -0.076 X_1 - 0.049 X_2 - 0.097X_3 + 13.87$	0.655	0.002	0.94
Soil temperature (°C)	$ST = 0.203 X_1 - 0.157 X_2 - 0.175 X_3 + 34.98$	0.820	0.003	1.90
Average		0.848	-----	1.372

Table 3. Mathematical relation of dependent and independent attributes for wireless based system

Dependent attributes	Equations	R ²	p value	Standard error
Temperature (°C)	$T = -0.033 X_1 - 0.245 X_2 + 41.36$	0.940	0.001	1.60
Relative humidity (%)	$RH = -0.467 X_1 + 0.38 X_2 + 44.7$	0.963	0.003	1.91
Evaporation (mm)	$E = -0.435 X_1 - .044 X_2 + 7.207$	0.864	0.002	0.46
Soil moisture (%)	$SM = -1.13 X_1 - 0.046 X_2 - 0.105 X_3 + 13.43$	0.677	0.001	0.95
Soil temperature (°C)	$ST = -0.908 X_1 - 0.132 X_2 - 0.173 X_3 + 34.49$	0.872	0.002	1.32
Average		0.863	-----	1.24

Table 4. Mathematical relation of dependent and independent attributes

Dependent attribute (Y)	Equations	Standard error	R ²	Independent attribute
Plant height	$Y = 3X_1 + 3.24X_2 + 0.92X_3 + 7.48$	7.18	0.914	
Number of leaves	$Y = 3.2X_1 + 1.07X_2 + 0.08X_3 + 3.98$	2.53	0.525	X ₁ = Irrigation System
Number of branches	$Y = 1.7X_1 + 1.433X_2 + 0.047X_3 - 4.17$	1.60	0.514	X ₂ = Irrigation Water Quality
Number of fruits	$Y = 2.1X_1 + 2.1X_2 + 0.0083X_3 - 0.950$	2.61	0.499	X ₃ = Days after transplanting
Yield	$Y = 2068.33X_1 + 1261.667X_2 + 31079.16$		0.819	

The observation for plant height, number of leaves, number of branches, number of fruits and yield with respect to irrigation system, water quality and days after transplanting were analysed. All the data collected from the field were analysed in the SPSS software for the regression analysis to derive the standard equation in form of $y = ax_1 + bx_2 + cx_3 + d$. The coefficients (a, b, c and d) of variable (X₁, X₂, X₃) were calculated by the software and are shown in Table 4. All the values of coefficients were placed in the standard regression equations for plant height, number of leaves, number of fruits, number of branches and yield.

The results reveal that all the independent attributes affected the plant height, number of leaves, number of fruits, number of branches and yield. The optimum value of various levels of attributes arrived from results of irrigation systems and regression analysis (Table 5).

The value of standard error and R² are 7.18 and 0.914 respectively indicate that the irrigation system, water quality and days after transplanting have strong relationship with plant height.

The value of standard error for number of leaves, number of branches and number of fruits was calculated as 2.53, 1.60 and 2.61 respectively. The value of R² for number of leaves, number of branches and number of fruits was calculated as 0.525, 0.514 and 0.499 respectively.

Table 5 shows that the optimum value of irrigation system for best combination of independent attributes of both the irrigation system. Plant height, number of leaves, number of branches, number of fruits and yield for wireless based drip irrigation system (IS₂) was higher by 4.44, 20.59, 25, 11.54 and 4.62 percent than the wired based drip irrigation system (IS₁). The optimum plant height of 92 cm was observed for treated fruit processing wastewater (WQ₂) with wireless based irrigation system (IS₂).

The results indicate that the optimum value of plant height, number of leaves, number of branches, numbers of fruits and the optimum yield was higher for wireless based irrigation system (IS₂) with treated fruit processing wastewater (WQ₂) in comparison to wired based irrigation system. Hence, it reveals that treated fruit

Table 5. Maximum and optimum value of irrigation system

Parameter	Maximum value				Increase percentage in parameter with wireless irrigation system	Combination of Independent attributes
	Wired irrigation System (IS ₁)		Wireless irrigation System (IS ₂)			
	Water quality (WQ ₁)	Water quality (WQ ₂)	Water quality (WQ ₁)	Water quality (WQ ₂)		
Plant height (cm)	84	88	88	92	4.44	WQ ₂ (IS ₂)
Number of leaves	13	14	16	18	20.59	WQ ₂ (IS ₂)
Number of branches	5	7	7	9	25.00	WQ ₂ (IS ₂)
Number of fruits	10	13	12	14	11.54	WQ ₂ (IS ₂)
Yield (ton/ha)	34.25	35.31	36.07	36.86	4.62	WQ ₂ (IS ₂)
Best combination	WQ ₂ (IS ₂)					

processing wastewater (WQ₂) in wireless based system (IS₂) was superior combination because of more precise irrigation and fertigation in wireless based system. Similar result was reported earlier (23).

Quality parameters of tomato

The influence of different irrigation treatments and different emitter types on quality parameters of tomato such as protein, carbohydrates, fats, ash and crude fibre are presented in Table 6.

The result shows that quality parameters of treated fruit processing wastewater (TFPWW) is better than ground water for wireless based automated drip irrigation system used in the study as it has better quality. Quality of tomato depends on amount of lycopene and dry matter within it. TFPWW contains maximum amount of lycopene (4.50 mg/100 g) and maximum amount of dry matter (6.67 %). Similar result was reported by previous researchers (24). This is due to the essential micronutrient present in the treated fruit wastewater from fruit processing plant was available during growing period.

Based on the observation for plant height, number of leaves, number of fruits, number of branches, yield and quality parameters with respective dripper types and water quality, the wireless irrigation system was evaluated. From the quality parameters of irrigation and emitter clogging test result, it is further concluded that TFPWW is better than ground water for wireless based automated drip irrigation system used in the study as it has better observations in independent and dependent parameters.

Conclusion

The wireless based automated drip irrigation system has proven to be easy to use and highly effective in comparison to wired based irrigation system in terms of enhanced yield and productivity of the

tomato crop. The maximum tomato yield was recorded under the irrigation regime involving application of treated fruit processing wastewater (WQ₂) with pressure compensating dripper. The TFPWW obtained from the fruit processing plant, had more content of micro and macro nutrients and therefore it is a better viable option for tomato crop. Application of treated fruit processing waste promises a better-quality crop produce (as observed for tomato crop in terms of enhanced dry matter, carbohydrates, lycopene and sugar content) as compared to conventional groundwater irrigation. The crop growth and yield attributes were further compared for both wireless and wired based irrigation systems through mathematical optimisation of both dependent attributes, such as temperature, relative humidity, evaporation, soil moisture and soil temperature as well as crop growth attributes including plant height, number of leaves, number of branches, number of fruits and yield. Based on the regression analysis, better performance was observed for the wireless based irrigation system compared to the wired based irrigation system. Wireless based irrigation system has strong relationship and less standard error as compared to wired based irrigation system.

Acknowledgements

Authors would like to acknowledge the support provided by their host Institution for completing the work. Acknowledgements are also due to M/s Jain Irrigation Systems Ltd., Jalgaon, Maharashtra, India for conferring Jain Irrigation Research Scholarship to Sandeep Kumar Pandey to carry out this research work.

Authors' contributions

SKP, AKP and PKM designed the experimental framework. SKP, AKP, PKM, MK, PY and VK conducted the field trial experiments. SKP, AKP,

Table 6. Effect of different water treatments on the quality parameters of tomato

Sl. No.	Parameter	Ground water	Treated fruit processing wastewater
1	Protein (%)	0.91	0.92
2	Carbohydrates (%)	3.28	3.57
3	Fat (%)	0.08	0.08
4	Ash (%)	0.86	0.95
5	Crude fibre (%)	1.13	1.20
6	Lycopene (mg/100 g)	4.28	4.50
7	Reducing sugar (%)	2.28	2.17
8	Total sugar (%)	2.30	2.36
9	Moisture (%)	93.30	93.79
10	Dry matter (%)	6.27	6.67

PKM and VK analysed the data. AKS proofread the manuscript and performed the economic analyses. SKP, AKP, PKM and VK prepared the manuscript. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest Statement: Authors do not have any conflict of interests.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process: For preparation of the graphical abstract, generative AI (Perplexity) has been used to convert our conclusions into illustration form. After using this tool/service, all authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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