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Optimizing tomato production with IoT-enabled precision irrigation: A case study of water and fertilizer management

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ABSTRACT

Precision irrigation is key for increasing tomato yields, especially given the crop's high-water demands. This study uses Internet of Things (IoT) technology and wireless sensor networks for automated irrigation and fertigation to improve water and fertilizer management for two tomato varieties, 'Sahoo' and 'SVTD8323', addressing resource inefficiency and water scarcity. The research compares different irrigation thresholds: -23 kPa during the seedling stage (100% water availability) and -30 kPa from vegetative to maturity stages (80% water availability). Fertigation schedules include 100% (F1) and 75% (F2) of the recommended fertilizer dose against a control treatment (constant -23 kPa) using Indian Institute of Horticulture Research fertilizer guidelines. Results show that 'Sahoo' under IF1 and IF2 treatments had a 12.5% and 13.5% yield increase over the control, using 34.9% and 38.7% less water, respectively. For 'SVTD8323', yields increased by 4.8% and 12.5% with water savings of 35.9% and 29% under IF1 and IF2. Additionally, IF2 treatment for 'Sahoo' and 'SVTD8323' resulted in a 31% and 14% rise in the number of fruits per plant, and an 8% and 5.5% increase in fruit weight, respectively. Cost analysis indicated that the control incurred the highest costs, with benefit-to-cost ratios of 1.28 and 1.34 for 'Sahoo' under IF1 and IF2, and 1.11 and 1.42 for 'SVTD8323'. IoT-enabled irrigation at 75% RDF significantly improves yield and resource efficiency.

Key words: Automated irrigation, fertigation, sensors, IoT, yield.

INTRODUCTION

Precision farming, especially with the integration of IoT technologies, has brought significant advancements in agriculture by providing farmers with critical insights for informed decision-making. This approach is especially advantageous for crops such as tomatoes, which require precise management due to their specific and sensitive growth needs (Singh *et al.,* 16). As tomatoes require careful regulation of water and nutrients to achieve optimal growth and high-quality yields, they represent a prime candidate for IoT-based precision farming methods (Nangare *et al.,*10). One of the main challenges in tomato cultivation, especially in arid regions, is managing water deficits and nutrient supply throughout the growing season. In these areas, limited rainfall makes irrigation the primary means of meeting the water needs of tomato crops. Efficient irrigation systems are crucial for enhancing water use efficiency and minimizing waste. Traditional irrigation methods, such as overhead irrigation, are widely used but often associated with considerable water and nutrient loss (Argo and Biernbaum, 1; Rolfe *et al.,* 14). On the other hand, microirrigation techniques, like drip irrigation, have shown promise in reducing nutrient leaching and runoff by as much as 50% compared to conventional overhead systems (Hicklenton and Cairns, 5).

Drip irrigation, in particular, is highly effective in vegetable cultivation. It allows for precise water delivery directly to the root zone, reducing water loss and improving nutrient uptake (Sun *et al.,* 17). Studies have found that drip irrigation can increase tomato yields by 10% while reducing water usage by 50% when compared to traditional methods (Jiang *et al.,* 6). Additionally, drip systems optimize water and nitrogen use more effectively than conventional furrow irrigation (Aujla *et al.,* 2). However, despite these advantages, farmers often overlook the soil's water-holding capacity, resulting in imprecise irrigation practices. This can lead to the development of anaerobic conditions, reduced root respiration, and nutrient losses through runoff and deep percolation. The integration of IoT technologies into irrigation systems offers a practical solution to these challenges. IoT-enabled systems can monitor and control irrigation operations, streamlining processes and reducing labor requirements while achieving significant water savings over traditional practices (Gutiérrez *et al.,* 4). Soil moisture sensor-based irrigation systems, for instance, are instrumental in achieving efficient and precise watering by measuring soil moisture levels in the root zone and delivering water at optimal times. This approach prevents both under-watering, which

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stresses the plants, and over-watering, which disrupts the plants' oxygen metabolism and hampers growth (Wan *et al.,* 20). While previous research has explored the individual impacts of irrigation and fertilization on tomato yield, the combined effects across different growth stages remain less understood (Sibomana *et al.,* 15; Zhao *et al.,* 23). Experiments indicate that maintaining specific soil moisture thresholds, such as a lower limit of -50 kPa, supports safe growth and optimal tomato yields (Wan, 19).

This study seeks to refine irrigation practices and nutrient delivery according to crop growth stages using an IoT-enabled automated irrigation system, aiming to maximize tomato yield while conserving water and nutrients.

MATERIALS AND METHODS

The study took place from December 2022 to March 2023 on a 0.5-acre farm in Bengaluru North (13° 30.23′ N, 77° 31.03′ E). During the period, the minimum temperature ranged from 18°C to 30°C, while the maximum ranged from 21°C to 40°C, with total rainfall reaching 108 mm. The soil was sandy clay loam with a pH of 6.8, 0.4% organic matter, and available nitrogen, phosphorus, and potash levels of 331 kg/ha, 25 kg/ha, and 120 kg/ha, respectively. Two rounds of ploughing followed by disc harrowing were carried out before planting, and tomato seedlings were transplanted with a spacing of 0.30m × 0.45m in a 307 m² plot (0.076 acre). The experiment used a split-plot design with irrigation as the main-plot factor and fertigation as the sub-plot factor. The irrigation treatments (I) (main-plot) included maintaining soil moisture at -23 kPa during the seedling stage, decreasing to -30 kPa during vegetative and maturity stages (Zhai *et al.,* 22), and a control (C) where moisture stayed at -23 kPa. The water holding capacity of sandy clay loam soil is 1.8 inches per foot. The corresponding soil moisture values are 100% field capacity (FC) at -23 kPa, with 0.00 inches per foot below FC, and 80% FC at approximately -30 kPa, with soil moisture ~0.84 inches per foot below FC UNL Watermark Sensor Chart (Melvin and Martin, 7). The IoT-based irrigation system was programmed to activate when soil water potential (SWP) reached -30 kPa and turn off at -23 kPa, ensuring optimal moisture levels throughout the growth stages. Since 20% depletion from FC is considered little to no stress for tomato, we ensured that soil moisture remained within the desired water zone to prevent stress. A drip irrigation system was used for water application, with each plot (0.076 acres) having 500 discharge points spaced at 20 cm apart, each emitting 2 liters per hour (LPH). The total duration of irrigation varied by treatment (Table 1).

Table 1. Total number of liters of irrigation water used during the crop.

	Treatment	Duration of irrigation (hours)	Litres of water irrigated (L)	Water saved over control (%)
'Sahoo' variety	IF1	17.25	17,250	34.91
	IF2	16.25	16,250	38.68
	Control	26.5	26,500	0.00
'SVTD8323' variety	IF1	17.00	17,000	35.85
	IF2	18.75	18,750	29.25
	Control	26.50	26,500	0.00

The wireless sensor network, automated irrigation system and automated weather station used in this study was developed by Digite Infotech Pvt Ltd. Bengaluru, India (Fig. 2). The system comprises three types of solar-powered IoT nodes: (1) a soil water potential and soil temperature sensor, (2) a solenoid valve controller, and (3) a pump controller node. All 3 nodes are solar-powered and communicate with a Central Gateway wirelessly using the LoRa communication technique. For this study, each treatment had one Type 1 node and one Type 2 node.

The Digite AgWise mobile application allows a user to monitor soil/environmental sensor data and the status of the main pump/solenoid valves in real-time. The user can also set the irrigation control mode and trigger manual irrigation events.

Fertilizer treatments involved two levels: F1 with 100% Recommended Dose of Fertilizer (RDF) and F2 with 75% RDF, based on a schedule developed by Digite (Table S1). The control treatment followed ICAR–IIHR fertilizer recommendations. Watermark sensors were installed at 0.3m and 0.45m depths in each treatment for monitoring soil water potential (Eisenhauer *et al.,* 3). The average of these two sensor readings were considered for threshold-based irrigation for each verity separately (Fig. 1).

Experimental treatments were as follows: IF1: Threshold-based irrigation and 100% RDF. IF2: Threshold-based irrigation and 75% RDF. Control: Soil moisture below -20 kPa and 100% RDF.

Ten plants per treatment were selected for data collection on plant height and branch numbers at weekly intervals from 30 to 65 days after transplanting. Yield data included the number of fruits and their weight across six harvests. Data were statistically analyzed using Fisher's Least Significant Difference at a 5% probability level.

Profitability was calculated based Pramanik *et al.* (12) on costs, including labor at ₹75 per hour

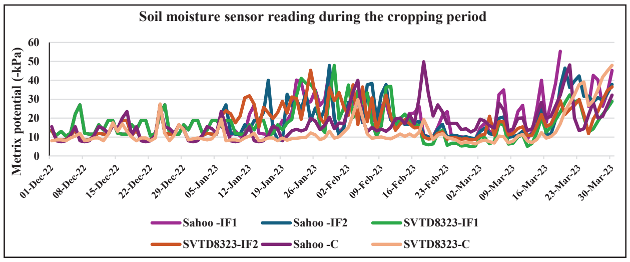

Fig. 1. Soil moisture sensor reading during the tomato cropping period.

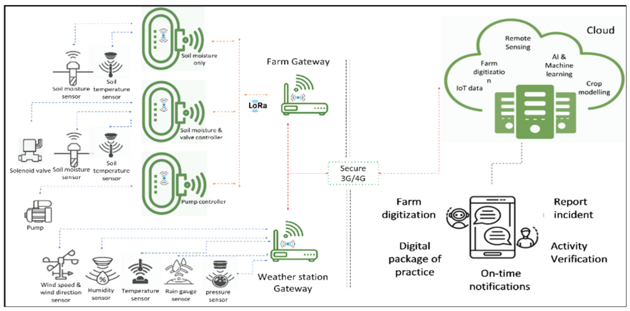

Fig. 2. Network architecture for a wireless sensor network and automation system. Consists of different types of IoT Nodes and are solar-powered and communicate with a Central Gateway wirelessly using the LoRa communication technique.

and machine work at ₹1000 per hour. Seedlings cost ₹0.9 each, and the market prices for nitrogen, phosphorus, and potash were ₹6, ₹22.5, and ₹16 per kg, respectively. Irrigation costs were estimated at ₹200 per 100,000 liters (Rohith *et al.,* 13), with electricity at ₹5.1 per kWh.

RESULTS AND DISCUSSION

The irrigation management employed in the study were compared between soil moisture sensor-based irrigation and control irrigation with detailed findings presented in Table 1. Specifically, the experimental plots featuring the "Sahoo" variety, when subjected to the F1 treatment, utilized 35% less water compared to the control treatment, while the F2 treatment exhibited an even greater reduction of 38.6 % in water usage. Similarly, for the 'SVTD8323' variety, the F1 treatment showcased a reduction of 35.8 % in water usage compared to the control treatment, with the F2 treatment demonstrating a slightly lower but still substantial reduction of 29 %. The significant reduction in water consumption observed in the fertigation treatments, particularly when combined with precision sensor-based irrigation, highlights the efficiency and resource-saving potential of such approaches. These findings align with the broader context of sustainable agriculture, where optimizing irrigation practices is crucial for conserving scarce water resources while maintaining or even enhancing crop yields (Palconit *et al.,* 11).

During the vegetative growth stage, plant height and the number of branches per plant were monitored at weekly intervals from 30 to 65 DAT. For the 'Sahoo' variety, at 30 DAT, the plant height was recorded as 25 cm, 29 cm, and 31 cm in control, IF1 and IF2 respectively. Subsequently, by 65 DAT heights reaching 108.04 cm, 108.125 cm, and 108.2 cm, in control, IF1 and IF2 respectively. This trend suggests that the IF1 and IF2 treatments facilitated robust crop growth from the vegetative to flowering stage. Similarly, for the 'SVTD8323' variety, plant height at 30 DAT was 26.5 cm, 30 cm, and 30.3 cm in the control, IF1, and IF2 treatments, respectively. By 65 DAT, plant heights were recorded as 107.9 cm, 111.9 cm, and 112.5 cm in the control, IF1, and IF2 treatments, respectively (Fig. 3a).

Moreover, the fertilizer treatments not only increased plant height but also contributed to a higher number of branches. For the 'Sahoo' variety, the total number of branches per plant at 30 DAT was 3.3 in the control, 3.5 in the IF1 treatment, and 3.7 in the IF2 treatment. By 65 DAT, these numbers rose to 26.8, 26.7, and 27.93 branches per plant in the control, IF1, and IF2 treatments, respectively. Similarly, for the 'SVTD8323' variety, the total number of branches per plant at 30 DAT was 3.1, 3.2, and 3.9 in the control, IF1, and IF2 treatments, respectively. By 65 DAT, these numbers increased to 25.5, 27.72, and 26.6 branches per plant in the control, IF1, and IF2 treatments, respectively (Fig. 3b). Our results indicate

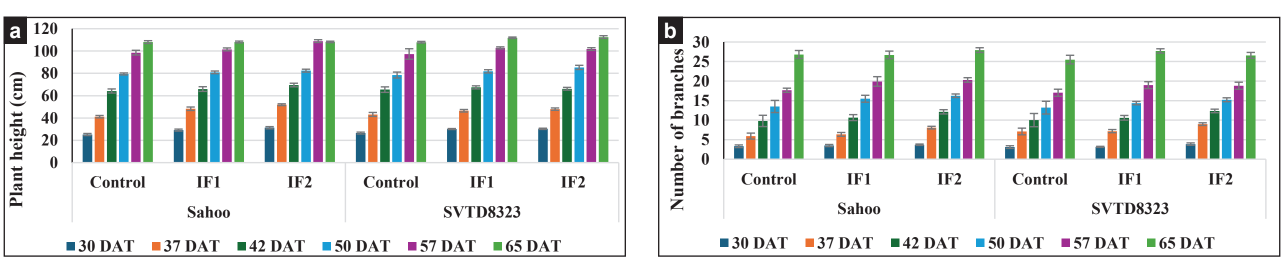

Fig. 3. Observation on plant height (a) and number of branches (b) at seven-day intervals from 30 DAT to 65 DAT.

that fertigation positively influenced plant growth and development. The observed increases in plant height and the number of branches are consistent with previous studies that have demonstrated the beneficial effects of optimized fertilizer application on tomato growth (Palconit *et al.*, 11; Tesfay *et al.*, 18).

The number of fruits per plant harvested in each treatment was recorded from labelled plants. The response of the 'Sahoo' variety in the experimental treatments exhibited a noteworthy increase in the number of fruits per plant, with increments of 14% and 31% observed in the IF1 and IF2 treatments, respectively, compared to the control treatment. Similarly, SVTD 8323 showed increased numbers of fruits per plant by 12.7% and 14% in the IF1 and IF2 treatments, respectively, over the control treatment (Fig. 4).

The yield per hectare was calculated for both the 'Sahoo' and 'SVTD8323' varieties across different treatments, including the control, F1, and F2 treatments, as presented in Figure 6a. In the 'Sahoo' variety, the yield per hectare was observed to be 25.6 tons in the control treatment, while the F1 and F2 treatments yielded 28.8 and 29.1 tons per hectare, respectively. Similarly, for the 'SVTD8323' variety, the control treatment yielded 27.5 tons per hectare, while the F1 and F2 treatments resulted in yields of 29 and 30.9 tons per hectare, respectively.

Furthermore, the 'Sahoo' variety exhibited a remarkable increase in yield in the F1 and F2 treatments compared to the control treatment, with increments of 12.5% and 13.5%, respectively. Similarly, the 'SVTD8323' variety showed an increase in yield of 4.8% and 12.5% in the F1 and F2 treatments, respectively, over the control treatment (Fig. 5). Fertigation treatments also led to a substantial increase in fruit yield and quality. The higher number of fruits per plant and increased fruit weight observed in the fertigation treatments are in line with previous research on the positive impact of optimized fertilizer and irrigation management on tomato fruit yield and quality (Tesfay *et al.,* 18; Monte *et al.,* 8; Mukherjee *et al.,* 9; Wang and Xing, 21; Zhuo *et al.,* 23).

Table 2 provides a comprehensive overview of the cost dynamics associated with tomato cultivation under different treatment per hectare. Through a detailed breakdown of various cost components including labour, materials, fertilizers, plant protection, irrigation, and electricity charges, the table offers valuable insights into the financial implications of different cultivation practices. By comparing the control treatment with the F1 and F2 treatments, which vary in fertilizer application rates and irrigation management. This analysis facilitates informed decision-making, allowing growers to optimize resource allocation, maximize profitability, and implement cost-effective cultivation strategies tailored to their specific needs and constraints.

Table 3 summarizes the per-Acre profitability in tomato production. It provides data for two tomato varieties, 'Sahoo' and SVTD 8323, across various parameters including yield, gross returns, total cost of cultivation (Cost A and Cost B), net returns, and the benefit-to-cost ratio (BC ratio). Notably, the BC ratio was found to be highest in the F2 treatment, where 75% of the recommended dose of fertilizer was applied alongside soil moisture maintained at -30 kPa. Specifically, the BC ratio for the 'Sahoo' variety in the F2 treatment was 1.34, while for the 'SVTD8323' variety, it was 1.42. The findings of this study underscore the economic viability and sustainability of precision fertigation and irrigation techniques. By reducing water consumption without compromising yield, these approaches can contribute to significant cost savings for farmers. Additionally, the increased yield

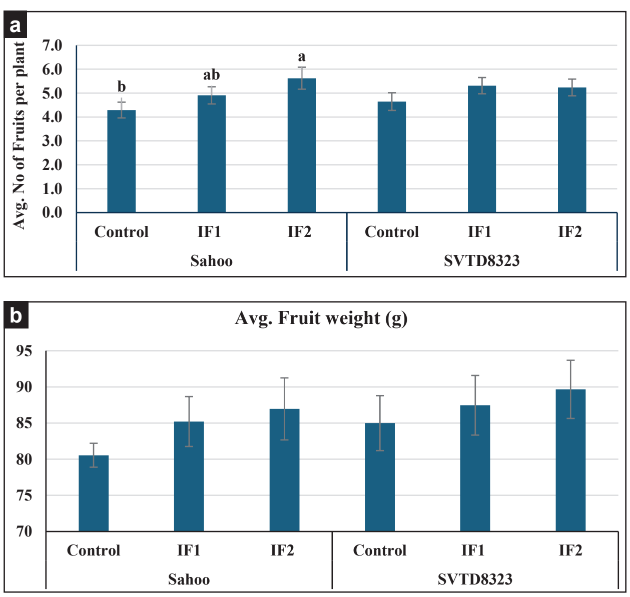

Fig. 4. Observations on number of fruits per plant at harvest. a) Average number of fruits harvest per plant b) Average fruit weight harvested per plant over control.

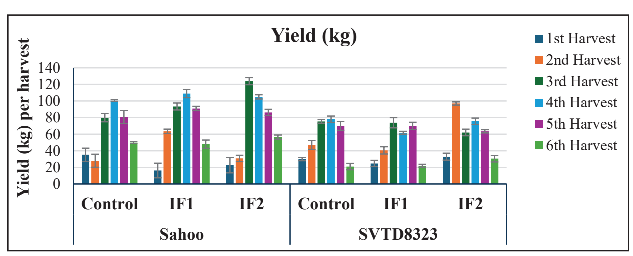

Fig. 5. Yield per harvest.

Table 2. Cost of cultivation per acre in tomato cultivation.

Cost of cultivation per acre		Control		IF1		IF2	
Sl. No	Particulars	Sahoo	SVTD8323	Sahoo	SVTD8323	Sahoo	SVTD8323
1	Hired human labour (man day) (₹ 600/ day wage)	23,000	23,000	23,000	23,000	23,000	23,000
2	Machine labour (₹)	6,000	6,000	6,000	6,000	6,000	6,000
3	Planting material (₹)	10,350	10,350	10,350	10,350	10,350	10,350
4	Fertilizer cost (₹)	13,742	13,742	13,568	13,568	9,639	9,639
5	Plant protection (₹)	6,710	6,710	6,710	6,710	6,710	6,710
6	Irrigation (₹)	3,442	3,442	2,240	2,208	2,110	2,435
7	Electricity charges (₹)	1,260	1,260	820	808	773	892
8	Soil moisture monitoring IoT system (₹)	20,000	20,000	20,000	20,000	20,000	20,000
9	Cost A (Σ item 1-7)	84,504	84,504	82,688	82,644	78,582	79,026
10	Land rent (₹)	25,000	25,000	25,000	25,000	25,000	25,000
11	Interest on fixed capital	450	450	450	450	450	450
12	Cost B (Σ item 8-10)	1,09,954	1,09,954	1,08,138	1,08,094	1,04,032	1,04,476

Table 3. Per acre profitability of tomato cultivation.

Per acre profitability in tomato production		Control		IF1		IF2	
Sl. No	Particulars	Sahoo	SVTD8323	Sahoo	SVTD8323	Sahoo	SVTD8323
1	Yield (t ac^{-1})	10.27	11.02	11.55	10.04	11.66	12.40
2	Gross returns (₹)	123,226	132,263	138,645	120,494	139,905	148,778
3	Cost A (Σ item 1-7, table 2)	84,504	84,504	82,688	82,644	78,582	79,026
4	Cost B (Σ item 8-10, table 2)	109,954	109,954	108,138	108,094	104,032	104,476
5	Net returns (₹)	13,273	22,310	30,507	12,400	35,872	44,302
6	Benefit to cost ratio (cost B divided through gross returns)	1.12	1.20	1.28	1.11	1.34	1.42
7	Water productivity ($L^{-1}kg^{-1}$ $plant^{-1}$)	77.25	71.97	44.75	50.75	41.78	45.32

and improved fruit quality can lead to higher market prices, further enhancing the economic benefits of precision agriculture. Water productivity, expressed as kg of yield per liter of water applied, showed significant improvement. The control treatment had the lowest water productivity (77.25 L/kg for 'Sahoo' and 71.97 L/kg for 'SVTD8323'), while IF1 (44.75 L/kg for 'Sahoo', 50.75 L/kg for 'SVTD8323') and IF2 (41.78 L/kg for 'Sahoo', 45.32 L/kg for 'SVTD8323') exhibited higher water use efficiency. These results underscore the potential of precision irrigation to optimize water use without yield penalties.

Conclusions highlight that sensor-based automated irrigation helps reduce groundwater contamination and soil salinity, while simultaneously increasing crop yield and reducing the use of water and fertilizers. Traditional methods often lead to excess water and fertilizer leaching, but sensor-based systems optimize water concentration in the root zone, boosting nutrient uptake and plant growth. The study demonstrated that optimized irrigation practices significantly increased plant height, branch number, and yield by 4.8% to 13.5%, with water consumption reduced by 29% to 39%. These techniques are vital for sustainable agriculture, optimizing resource use, and enhancing productivity.

AUTHORS' CONTRIBUTION

Conceptualization of research (MS, VP); Designing of the experiment (MS, NK); Contribution

of experimental materials (NK, SR); Execution of experiment and data collection (MS, NK); Analysis of data and preparation of the manuscript (MS).

DECLARATION

The authors declare that they have no conflict of interest.

REFERENCES

1. Argo, W. R. and Biernbaum, J. A. 1994. The effect of irrigation method, water-soluble fertilization, replant nutrient charge, and surface evaporation on early vegetative and root growth of poinsettia. *J. Am. Soc. Hortic. Sci.* **120**: 163–169.

2. Aujla, M. S., Thind, H. S. and Buttar, G. S. 2007. Fruit yield and water use efficiency of eggplant (*Solanum melongema* L.) as influenced by different quantities of nitrogen and water applied through drip and furrow irrigation. *Sci. Hortic.* **112**: 142–148.

3. Eisenhauer, D. E., Martin, D. L, Heeren, D. M. and Hoffman, G. J. 2021. Irrigation systems management, *Am. Soc. Agric. Biol. Eng.,* doi:10.13031/ISM.2021.1

4. Gutiérrez, J., Villa-Medina, J. F., Nieto-Garibay, A. and Porta-Gándara, M. Á. 2013. Automated irrigation system using a wireless sensor network and GPRS module. *IEEE Trans. Instrum. Meas.* **63**: 166–176.

5. Hicklenton, P. R. and Cairns, K. G. 1996. Plant water relations and mineral nutrition of containerized nursery plants in relation to irrigation method. *Can. J. Plant Sci.* **76**: 155–160.

6. Jiang, H. M., Zhang, J. F., Song, X. Z., Liu, Z. H., Jiang, L. H. and Yang, J. C. 2012. Responses of agronomic benefit and soil quality to better management of nitrogen fertilizer application in greenhouse vegetable land. *Pedosphere* **22**: 650–660.

7. Melvin, S. R. and Martin, D. L. 2018. Irrigation scheduling strategies when using soil water data. EC 3036. University of Nebraska-Lincoln Ext.

8. Monte, J. A., Carvalho, D. F. d., Médici, L. O., Silva, L. D. B. and Pimentel, C. 2013. Growth analysis and yield of tomato crop under different irrigation depths. *Rev. Bras. Eng. Agríc. Ambient.* **17**(9): 926-931.

9. Mukherjee, S., Dash, P. K., Das, D. and Das, S. 2023. Growth, yield and water productivity of tomato as influenced by deficit irrigation water management. *Environ. Process.* **10:** 10. https://doi.org/10.1007/s40710-023-00624-z

10. Nangare, D. D., Singh, Y., Kumar, P. S. and Minhas, P. S. 2016. Growth, fruit yield and quality of tomato (*Lycopersicon esculentum* Mill.) as affected by deficit irrigation regulated on phenological basis. *Agric. Water Manag.* **171**: 73–79.

11. Palconit, M. G. B., Macachor, E. B., Notarte, M. P., Molejon, W. L., Visitacion, A. Z., Rosales, M. A. and Dadios, E. P. 2020. IoT-based precision irrigation system for eggplant and tomato. 9th *Int. Symp. Comput. Intell. Ind. Appl.* (ISCIIA 2020).

12. Pramanik, S., Tripathi, S. K., Ray, R. and Banerjee, H. 2014. Economic evaluation of drip-fertigation system in Banana cv. Martaman (AAB, Silk) cultivation in the new alluvium zone of West Bengal. *Agric. Econ. Res. Rev.* **27**(347-2016-17115): 103-109.

13. Rohith, G. V., Rashmi, K. S., Hamsa, K. R., Lekshmi, U. D., Rajeshwari, D., Manjunatha, A. V. and Olekar, J. 2015. Incorporating the cost of irrigation water in the currently underestimated cost of cultivation: an empirical treatise. *Indian J. Agric. Econ.,* **70**: 1-14, 10.22004/ag.econ.230067

14. Rolfe, C. J., Currey, A. and Atkinson, I. 1994. Horticultural research; NSW agriculture; nursery industry association of australia. managing water in plant nurseries: A guide to irrigation, drainage and water recycling in containerised plant nurseries; NSW Agriculture: Wollongbar, NSW, Australia.

15. Sibomana, I. C., Aguyoh, J. N. and Opiyo, A. M. 2013. Water stress affects growth and yield of container grown tomato (*Lycopersicon esculentum* Mill) plants. *Glob. J. Bio-Sci. BioTechnol.* **2**: 461-466.

16. Singh, D., Biswal, A. K., Samanta, D., Singh, V., Kadry, S., Khan, A. and Nam, Y. 2023. Smart high-yield tomato cultivation: precision irrigation system using the Internet of Things. *Front. Plant Sci.* **14**: 1239594. doi: 10.3389/fpls.2023.1239594

17. Sun, Y., Hu, K. L., Fan, Z. B., Wei, Y. P., Lin, S. and Wang, J. G. 2013. Simulating the fate of nitrogen and optimizing water and nitrogen management of greenhouse tomato in North China using the EU-Rotate_N model. *Agric. Water Manag*. **128**: 72–84. Doi. 10.1016/j.agwat.2013.06.016.

18. Tesfay, T., Berhane, A. and Gebremariam, M. 2019. Optimizing irrigation water and nitrogen fertilizer levels for tomato production. *Open Agric. J.* **13**: 198-206. DOI: 10.2174/1874331501913010198.

19. Wan, S. 2008. Effect of saline water on tomato growth and yield by drip irrigation in semi-humid regions of north China. *Trans. CSAE* **24**: 30–35.

20. Wan, X., Li, B., Chen, D., Long, X., Deng, Y., Wu, H. and Hu, J. 2021. Irrigation decision model for tomato seedlings based on optimal photosynthetic rate. *Int. J. Agric. Biol. Eng.*, **14**: 115–122.

21. Wang, X. and Xing, Y. 2017. Evaluation of the effects of irrigation and fertilization on tomato fruit yield and quality: a principal component analysis. *Sci. Rep.* **7**: 350.

22. Zhai, Y., Yang, Q. and Hou, M. 2015. The effects of saline water drip irrigation on tomato yield, quality, and blossom-end rot incidence: A case study in the south of China. *PLoS ONE*, **10**(11): e0142204. https://doi.org/10.1371/journal.pone.0142204

23. Zhao, F. Yoshida, H. Goto, E. and Hikosaka, S. 2022. Development of an irrigation method with a cycle of wilting partial recovery using an image-based irrigation system for high-quality tomato production. *Agronomy*. **12**: 1410.

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