From Tradition to Innovation: IoT-Enabled Precision Farming Strategies for Optimal Resource Use efficiency in Tomato Crop Management

Nirmal Kaliannan
Digite Infotech Pvt Ltd
Naveen Latha Sabapathi
Digite Infotech Pvt Ltd
Sushant Ranjan
Digite Infotech Pvt Ltd
Varun Prabhakar
Digite Infotech Pvt Ltd
Mahesh Salimath (mahesh.salimath@digite.com)
Digite Infotech Pvt Ltd

Research Article

Keywords: Precision agriculture, Tomato, Fertigation, Soil water sensor, Internet of Things, profitability

Posted Date: January 12th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-3770030/v1

Additional Declarations: No competing interests reported.

Abstract

This study investigates the response of two varieties of plants, Sahoo and SVTD8323, to different fertilizer treatments. The Sahoo variety showed a quick response to the fertilizer treatments, with F1 and F2 treatments resulting in a 17% and 26% increase in plant height at 40 DAT, respectively. Both varieties showed an increase in the number of branches, with F2 treatment resulting in a 24% and 26% increase in Sahoo and SVTD8323, respectively. Both the varieties showed an increase in fruit weight, with Sahoo showing a 5.8% and 7.9% increase in fruit weight over the control at F1 and F2 treatment, respectively, while SVTD8323 showed a 2.9% and 5.5% increase in fruit weight over the control at F1 and F2 treatment, respectively. Both varieties followed a parabolic curve in yield per harvest across treatments, with Sahoo showing a 12.5% increase in yield at F1 treatment and a 13.5% increase at F2 treatment over the control treatment. Similarly, SVTD8323 showed a 12.5% increase in yield at F2 treatment over the control treatment. In a nutshell both the varieties consumed 29 to 39% lesser water and 25% lesser fertilizer than respective control treatment. The benefit to cost ratio was highest at F2 treatment in both varieties, with a ratio of 2.14 in Sahoo and 2.27 in SVTD8323, indicating that the IoT enabled precision farming profitable.

Introduction

IoT-enabled precision farming has revolutionized agriculture by providing farmers with valuable insights and data that can help them make informed decisions about their crops (Atalla et al., 2023). This technology is particularly useful for crops such as tomatoes, which require precise care and attention to produce a high-quality yield (Singh et al., 2023).

Tomato is an important and widely grown solanaceous vegetable crop around the world, both for fresh market and processing. It is an important source of vitamins and minerals. In India, tomato covers an area of about 8.12 lakh ha with a production of 20.34 million tons and productivity of 20.7 t ha-1 (Advanced estimates, MoA&FW 2022). Annual production of tomato in 2022-23, Karnataka stands second across India after Madhya Pradesh (NABARD, 2023) and it is the need of the hour to find solutions for water deficit tomato cultivation. Even though there is significant production of tomato in India, the extent of cultivated land is limited and hence it is essential to exploit the potential of tomato production through proper agronomic practices. To realize maximum yield potential, management of water and nutrients is very important and precision farming is considered as one such approach.

Traditional irrigation practices, adopted by farmers, often lead to excess water being used. In addition, excess fertilizer applied in the pursuit of higher yields result in higher rates of soil salinization and groundwater contamination (Zhai et al., 2015). Therefore, a better understanding of plant periodical response to soil moisture and fertilizer is highly important to water and fertilizer management. Many studies have been conducted on the effect of irrigation or fertilizer on tomato yield (Wang & Xing 2017, Jaria & Madramootoo, 2013; Gemel et al., 2020). Nevertheless, a few studies investigate the combined effect of irrigation and fertilizers on tomato, and even fewer investigating its impact on different growth stages.

Precision irrigation has been recently seen as a growing field in agriculture to properly utilize water resources according to the real time requirements of plants in which the success is dependent on the monitoring and control strategies. In this regard, the Internet of Things (IoT) and Wireless Sensor Network (WSN) are deemed efficient enabling technologies to provide real-time monitoring of the plants, soil, and the related environment conditions (Adeyemi et al., 2018; Jimeneza et al., 2020).

By monitoring and controlling environmental factors using IoT precision farming, farmers can reduce water and fertilizer usage while increasing yield, which not only saves money but also helps to protect the environment.

Materials and methods

Experimental Site and Land preparation

The study was carried out from December 2022 to March 2023 at a farm in Bengaluru North (Latitude 13.503890˚ N, Longitude 77.517130 E.). The mean monthly minimum temperature varied from 18 °C to 30 °C and mean monthly maximum temperature varied from 21°C to 40°C during the study period. The total rainfall during the cropping period was 108 mm. The soil in the experimental plot was clay-loam with a pH 6.8, EC 0.06 dS/m, 0.4% organic matter, and 331 kg/ha nitrogen, 25 kg/ha phosphorus, and 120 kg/ha potash availability. Two deep ploughings followed by disc harrowing were performed before planting. The tomato seedlings were transplanted with spacing of 0.3 x 0.45 m.

Experimental Strategies and sensor placement

Tomato seedlings of Sahoo and SVTD 8323 were purchased from a nursery and hardened at the experimental site. The experiment plot size was 0.038 Ac and had three fertigation treatments (control, F1 & F2) along with two irrigation treatments, a soil water potential threshold-based treatment and a control treatment. Irrometer Watermark soil water potential sensors were installed (two sensors per strategy per variety) within a treatment and at two different depths. One sensor was installed at a depth of 0.3 m and the other was installed at a depth of 0.45 m. The average of these two sensor readings were considered for threshold-based irrigation for each verity separately.

Fertigation Treatments and irrigation scheduling: The experimental irrigation treatment consisted of the following methodology: Soil moisture maintained for F1 and F2 treatments during crop establishment – 20kPa (10 DAT; Days After Transplanting), vegetative stage – 40kPa (11–40 DAT) and flowering to harvest – 50kPa (41–110 DAT) (Zhai et al., 2015). For control treatment traditional daily irrigation was followed for an hour if there was less than 0.02mm rainfall.

The drip irrigation system had lateral discharge points at 20cm distance with 2 LPH (liters per hour). The automated irrigation control system (AgWise IoT automation - Developed by Digite infotech) started irrigating when the average of the two Watermark sensors reached the corresponding threshold and stopped irrigating once senor readings reach field capacity. Three treatments of fertigation levels at 100%

RDF (F1), 75% RDF (F2) and control of the Recommended Dose of Fertilizer (RDF) were employed. Fertigation scheduling and nutrient management established by Digite was followed in F1 and F2 treatments and the control treatment followed ICAR - IIHR fertilizer recommendation.

Data Collection

Ten plants were randomly selected from the middle rows of the treatments and data was collected on plant height, and number of branches. Observations on plant height, number of branches set were recorded at seven-day intervals from 30 DAT to 65 DAT and their average values were considered for further statistical analysis. The yield attributes such as number of fruits per plants harvested and weight of the fruits were recorded across six harvests.

Statistical Analysis and Economic analysis

The data obtained for different parameters were statistically analyzed. Statistical significance between the mean of individual strategies was assessed using Fisher's Least Significant Difference (LSD) at a 5% probability level (Dahiwalkar et al., 2004).

The profitability of tomato production was measured using the concept of Cost A and Cost B (Pramanik et al., 2014, Pramanik & Patra, 2016; Shelke et al., 2016). One man-day consisted of 8 hours of work. Labour cost was evaluated at the rate of Rs. (₹) 75 per hour (Table 2). Machine labour was assessed at the rate of Rs. (₹) 1000 per hour. The tomato seedlings were purchased for Rs. (₹) 0.9 per seedling. The prevailing market rates for nitrogen, phosphorus, and potash fertilizers were Rs. (₹) 6, 22.5, 16 per kg, respectively and manures (Table 2). One cartload of farmyard manure was considered at four quintals, and its prevailing price was Rs. (₹) 500 per quintal. Interest on fixed capital was calculated at a rate of 1.8%. Irrigation cost calculated based on average extraction cost of Rs. 200 for 100,000 litre for borewell irrigation across Karnataka state, India (Rohith et al., 2015). The tomato yield was sold at an average price of Rs. (₹) 10/kg. Electricity charges calculated by considering Borewell pump 5hp = 3.73kW (5hp pump would be able to support 1 acre of Tomato) and commercial electricity in Karnataka state, India is Rs. (₹) 5.1 per KWh. The total irrigation motor run hour was considered for each strategy of electricity consumption.

Wireless sensor network and automated irrigation system

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. 1).

Wireless sensor network: The system consists of 3 different types of IoT Nodes: 1) A Soil Water Potential Sensor + Soil Temperature Sensor, which is used to measure soil water potential and temperature at a desired location only. 2) A Soil Water Potential Sensor + Soil Temperature Sensor + Solenoid Valve Control, which measures soil water potential, soil temperature at a desired location, and has an actuator that can operate a solenoid valve used to control water flow to a desired irrigation zone. 3) A Pump Controller node which is used to control the main irrigation pump and is designed to work with any automatic pump starter. Type 1 and 2 Nodes are designed and calibrated to work with the Irrometer Watermark sensor. All 3 nodes are solar-powered and communicate with a Central Gateway wirelessly using the LoRa communication technique. There are three primary roles for the Central Gateway: 1) To collect sensor data from all the nodes and 2) To send the data to the Digite cloud platform via a 4G mobile network connection 3) To manage the automation and control logic for all the nodes and irrigation zones.

Automated irrigation system

The system is designed to automate the control of the main irrigation pump and solenoid valves within a field based on 3 control modes. The first is a sensor-based control mode, where irrigation to a specific zone is triggered by the average of all soil water potential sensors within that zone, and it stops after a predefined time. The second is a recurring timer-based control mode, where a fixed amount of water is required to be delivered to a zone at predefined intervals. The third is a completely manual control mode, where the user can initiate predefined non-recurring irrigation events. For this study, each strategy zone had one Type 1 node and one Type 2 node, where each node was connected to 2 soil water potential sensors for a total of 4 soil water potential sensors per zone.

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.

Results and discussion

Growth parameters During the vegetative growth stage the plant height, number of branches per plant of both the varieties were recorded on a week interval from 30 DAT to 65 DAT.

The plant height of Sahoo variety at 30 DAT was 25cm in control, 29cm in F1, and 31cm in F2 treatments. The treatments F1 and F2 showed increase in plant height till 57 DAT over control. At 57 DAT, the Sahoo plant height was 98.55cm in control, 101.5cm in F1 and 108.9cm in F2 treatments. These results indicated that the F1 and F2 treatments helped to establish rigours crop growth during the vegetative to flowering stage. Similarly, the plant height of SVTD8323 at 30 DAT was 26.5cm in control, 30cm in F1, and 30.3cm in F2 treatments and at 57 DAT plant height was 97.35cm in control, 102.86cm in F1, and 101.8cm in F2 treatments.

The fertilizer treatments increased not only the plant height, but also influenced to increase in number of branches. The total number of branches per plant of Sahoo variety at 30 DAT were 3.3 in control, 3.5 in F1 and 3.7 in F2 treatments. At 57 DAT, the number of branches per plants were 17.65 in control, 19.9 in F1 and 20.3 in F2 treatments. The variety SVTD8323 had total number of branches per plant were 3.1 in control, 3.2 in F1 and 3.9 in F2 treatments. At 57 DAT, the number of branches per plants were 17 in control, 19 in F1 and 18.8 in F2 treatments. The findings of plant height and number of branches per plant indicated, that the plant height increased during the vegetative to flowering stage and number of branches increased during flowering to fruiting stage. Quite similar experimental results were showed with optimized fertilizer increased plant height and number of branches in tomato (Palconit et al., 2020; Moncada et al., 2020; Traoré et al., 2022). Similarly, findings in tomato indicate that optimising the irrigation water and fertilizer levels influence higher plant height, branches, and yield (Tesfay et al., 2019).

Number of fruits and fruit weight Number of fruits per plants harvested in each treatment plant was recorded. The response of Sahoo in the experimental treatments showed increase in number of fruits per plant by 14% and 31% in F1 and F2 treatments respectively over control treatment. Similarly, SVTD 8323 showed increased number of fruits per plants by 14% and 12.7% in F1 and F2 treatments respectively over control treatment (Fig 3a and 3b). Supporting to this finding Tesfay et al., (2019) showed that optimised use of fertilizer and irrigation enhances the number of fruits per plants. The Sahoo variety showed 5.8% and 8% increase in fruit weight over the control at F1 and F2 treatment. The SVTD8323 variety showed 2.9% and 5.5% increase in fruit weight over the control at F1 and F2 treatment (Fig 4a and 4b). Similar trends of growth responses were obtained in other strategic study (Monte et al., 2013; Tesfay et al., 2019; Moncada et al., 2020; Traoré et al., 2022; Mukherjee et al., 2023).

Irrigation The quantity of irrigation between soil moisture sensor-based irrigation and traditional irrigation is tabulated in Table 1. The experimental plots with Sahoo variety with F1 treatment used 35% and F2 treatment used 38.6% lesser water respectively than control treatment. The variety SVTD8323 with F1 treatment used 35.8% and with F2 treatment used 29% lesser water than control treatment (Palconit et al., 2020).

Table 1: **Total number of liters of water irrigated during the crop.** Wherein Control 100% RDF: Indian Institute of Horticulture Research (IIHR) Recommended Dose of Fertilizer; F1 and F2 RDF: Digite Recommended Dose of Fertilizer.

Variety	Treatments	Total Number of discharge points per plot (@ distance of 20cm with 2 LPH)	Total duration of irrigation (hours) during the season	Total litres of water irrigated	% saved over control
Sahoo	F1	500	17.25	17,250	34.91
	F2	500	16.25	16,250	38.68
	Control	500	26.5	26,500	0.00
SVTD8323	F1	500	17.00	17,000	35.85
	F2	500	18.75	18,750	29.25
	Control	500	26.50	26,500	0.00

Yield and profitability Calculated yield per hectare in the Sahoo variety, the control, F1 and F2 treatments were 25.6, 28.8, and 29.1 tons per ha respectively. Similarly, in the SVTD8323 variety the control, F1 and F2 treatments yields were 27.5, 29 and 30.9 tons per ha respectively (Fig 5a). The Sahoo variety at F1 treatment showed 12.5% and at F2 treatment showed 13.5% increase in yield over the control treatment. The SVTD8323 variety at F1 treatment showed 4.8 % and at F2 treatment showed 12.5% increase in yield over the control treatment (Fig 5b). The results are consistent with that of Zhang et. al (2016) who found that irrigation at 80 % ET could save considerable amount of water and obtained largest yield. Similarly with moderate irrigation obtained higher yield in tomato (Wang & Xing, 2017; Tesfay et al., 2019; Zhuo & Hoekstra, 2017, Monte et al., 2013; Amala & Syriac, 2016).

Considering cost incurred during the tomato crop cultivation the benefit to cost (BC) ratio was estimated. The BC ratio was highest at F2 treatment (75% RDF and -50 kPa) 2.09 and 2.22 in Sahoo and SVTD 8323 varieties respectively (Table 2 and Table 3).

Table 2 Cost of cultivation per hectare incurred in tomato cultivation. Wherein Control 100% RDF: Indian Institute of Horticulture Research (IIHR) Recommended Dose of Fertilizer; F1 and F2 RDF: Digite Recommended Dose of Fertilizer

Cost of Cultivation incurred in per ha		Control (100% RDF + alternate day irrigation)		F1 treatment: 100% RDF + 50 kPa		F2 treatment: 75% RDF + 50 kPa	
Sl. No	**Particulars**	**Sahoo**	**SVTD 8323**	**Sahoo**	**SVTD 8323**	**Sahoo**	**SVTD 8323**
1	Hired human labour (man day) (₹ 600 per day labor wage)	26,000	26,000	26,000	26,000	26,000	26,000
2	Machine labour (₹)	8,000	8,000	8,000	8,000	8,000	8,000
3	Planting material (₹)	24,975	24,975	24,975	24,975	24,975	24,975
4	Fertilizer cost (₹)	13,742	13,742	13,568	13,568	9,639	9,639
5	Plant protection (L)	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	**Cost A (Σ item 1-7)**	**84,129**	**84,129**	**82,313**	**82,269**	**78,207**	**78,651**
9	Land rent (₹)	60,000	60,000	60,000	60,000	60,000	60,000
10	Interest on fixed capital	1,080	1,080	1,080	1,080	1,080	1,080
11	**Cost B (Σ item 8-10)**	**1,45,209**	**1,45,209**	**1,43,393**	**1,43,349**	**1,39,287**	**1,39,731**

Table 3 Per hectare profitability of tomato cultivation. Wherein Control 100% RDF: Indian Institute of Horticulture Research (IIHR) Recommended Dose of Fertilizer; F1 and F2 RDF: Digite Recommended Dose of Fertilizer

Per hectare profitability in Tomato production		Control (100% RDF + alternate day irrigation)		F1treatment: 100 % RDF + 50 kPa		F2 treatment: 75 % RDF + 50 kPa	
Sl. No	**Particulars**	**Sahoo**	**SVTD 8323**	**Sahoo**	**SVTD 8323**	**Sahoo**	**SVTD 8323**
1	Yield (t/ha)	25.67	27.55	28.88	25.10	29.15	31.00
2	Gross returns (₹)	2,56,722	2,75,549	2,88,844	2,51,029	2,91,468	3,09,954
3	Cost A (Σ item 1-7)	84,129	84,129	82,313	82,269	78,207	78,651
4	Cost B (Σ item 8-10)	1,45,209	1,45,209	1,43,393	1,43,349	1,39,287	1,39,731
5	Net Returns (₹)	1,11,513	1,30,340	1,45,451	1,07,680	1,52,181	1,70,223
6	Benefit to Cost ratio (cost B divided through gross returns)	1.77	1.90	2.01	1.75	2.09	2.22

Conclusion

Promotion of sensor based automated irrigation not only reduces the risk of groundwater contamination and soil salinity, but also increases yield while reducing irrigation water and fertilizers. In traditional irrigation practices, water percolates outside the rootzone due to excess irrigation resulting in fertilizer chemicals leaching into groundwater. With a sensor-based irrigation system, irrigated water is primarily concentrated in the root zone. Accordingly, plant roots can be able to take up and effectively utilize the nutrients and water, resulting in superior plant growth.

The study on growth parameters, fruit production, irrigation water usage, nutrient management and yield in two tomato varieties, Sahoo and SVTD8323, revealed significant insights into the impact of fertigation and irrigation practices. This study demonstrated that optimized fertilizer and irrigation practices have a substantially positive impact on tomato plant growth demonstrated by the 17–26% increase in plant height (Fig. 2a) and 24–26% increase in the number of branches (Fig. 2b). These findings align with previous research that emphasized the importance of proper fertilizer and irrigation management in achieving optimal growth and development in tomato plants. Both tomato varieties exhibited increased fruit production, with F2 treatments showing higher yield as compared to the control. The analysis of irrigation water usage indicated that the sensor-based irrigation system reduced water consumption by 29–39% compared to the control (Table 1). This reduction in water usage is a significant contribution to water conservation in agriculture, which is essential in regions facing water scarcity. The study's most noteworthy outcome was the enhanced yield in both tomato varieties due to the optimized combination of fertigation and irrigation practices. The increase in yield, ranging from 4.8–13.5%, (Fig. 5b) is a promising result, especially when considering the growing global demand for sustainable agricultural practices and efficient water management. In terms of profitability, the benefit-to-cost (BC) ratio was highest in the F2 treatment for both Sahoo and SVTD8323 varieties, indicating that this approach is not only environmentally sustainable but also economically viable. The results suggest that the 75% RDF of Digite fertigation schedule and – 50 kPa irrigation treatment combination holds great promise for maximizing both yield and profitability.

In summary, this research highlights the importance of tailored fertigation and irrigation practices in optimizing tomato growth, fruit production, and water and fertilizer conservation. It provides valuable insights for farmers and policymakers looking to enhance crop yield while efficiently managing water resources. These findings also align with previous research, reinforcing the idea that sustainable agricultural practices can significantly improve productivity and reduce environmental impacts.

Declarations

Author contribution

Nirmal Kaliannan: Validation, Supervision, **Navenn Latha Sabapathi**: Methodology, Supervision, **Sushant Ranjan**: Methodology, **Varun Prabhakar:** Methodology, Supervision, review and editing, **Mahesh Salimath:** Conceptualization, Supervision, Writing - original draft.

Funding This research was internally funded by Digite Infotech Private Limited, Bangalore, India

Data availability

The datasets generated and analysed in this study are available from the corresponding author upon reasonable request.

Ethical approval Note applicable for that section

Consent to participate Note applicable for that section

Consent to publication Note applicable for that section

Competing interests The authors declare no competing interests.

Acknowledgments

The authors thank Digite Infotech Pvt. Ltd for financial support to conduct the experiment.

References

1. Adeyemi, O., Grove, I., Peets, S., Domun, Y., & Norton, T. (2018). Dynamic neural network modeling of soil moisture content for predictive irrigation scheduling. *Sensors,* 18(10), 3408. https://doi.org/10.3390/s18103408

2. Amala, J., & Syriac, E. K. (2016). Standardization of fertigation schedule for tomato (Solanum lycopersicum L) under open precision farming. *Journal of Crop and Weed*, 12(2), 82-85.
3. Atalla, S., Tarapiah, S., Gawanmeh, A., Daradkeh, M., Mukhtar, H., Himeur, Y., ... & Daado, M. (2023). IoT-Enabled Precision Agriculture: Developing an Ecosystem for Optimized Crop Management. *Information,* 14, 205. https://doi.org/10.3390/info14040205
4. Dahiwalkar, S. D., Divekar, B. K., & Sonawane, D. A. (2004). Relative performance of fertigation on growth, yield, and quality of banana. *Journal of Maharashtra Agricultural University*, 29(2), 235-237. https://eurekamag.com/research/004/299/004299015.php
5. Jaria, F., & Madramootoo, C. A. (2013). Thresholds for irrigation management of processing tomatoes using soil moisture sensors in southwestern Ontario. *Transactions of the ASABE*, 56(1), 155-166. doi: 10.13031/2013.42597
6. Jimenez, A. F., Cardenas, P. F., Jimenez, F., Ruiz-Canales, A., & López, A. (2020). A cyber-physical intelligent agent for irrigation scheduling in horticultural crops. *Computers and Electronics in Agriculture,* 178, 105777. https://doi.org/10.1016/j.compag.2020.105777
7. Ministry of Agriculture & Farmers Welfare. (2022). Second Advance Estimates (2021-22) of Area and Production of Horticultural Crops released. Retrieved from https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/jul/doc202271470601.pdf
8. Moncada, A., Vetrano, F., Esposito, A., & Miceli, A. (2020). Fertigation Management and Growth-Promoting Treatments Affect Tomato Transplant Production and Plant Growth after Transplant. *Agronomy*, 10, 1504. https://doi.org/10.3390/agronomy10101504
9. Monte, J. A., Carvalho, D. F. d., Médici, L. O., Silva, L. D. B. d., & Pimentel, C. (2013). Growth analysis and yield of tomato crop under different irrigation depths. Revista Brasileira De Engenharia Agrícola E Ambiental, 17(9), 926-931. https://doi.org/10.1590/s1415-43662013000900003
10. Mukherjee, S., Dash, P. K., Das, D., et al. (2023). Growth, Yield, and Water Productivity of Tomato as Influenced by Deficit Irrigation Water Management. *Environmental Processes*, 10(10). https://doi.org/10.1007/s40710-023-00624-z
11. NABARD. (2023). Spiralling Tomato Prices: Issues and Concerns. Retrieved from https://www.nabard.org/auth/writereaddata/tender/2208232801soaring-tomato-prices-Issues-and-concerns.pdf
12. Palconit, M. G. B., Macachor, E. B., Notarte, M. P., Molejon, W. L., Visitacion, A. Z., Rosales, M. A., & Dadios, E. P. (2020). IoT-Based Precision Irrigation System for Eggplant and Tomato. In The 9th International Symposium on Computational Intelligence and Industrial Applications (ISCIIA2020).
13. Pramanik, S., & Patra, S. K. (2016). Growth, yield, quality, and irrigation water use efficiency of banana under drip irrigation and fertigation in the Gangetic plain of West Bengal. *World Journal of Agricultural Sciences*, 12(3), 220-228. doi: 10.5829/idosi.wjas.2016.12.3.1913
14. Pramanik, S., Tripathi, S. K., Ray, R., & Banerjee, H. (2014). Economic evaluation of drip-fertigation system in Banana cv. Martaman (AAB, Silk) cultivation in the new alluvium zone of West Bengal.

Agricultural Economics Research Review, 27(347-2016-17115), 103-109. doi: 10.5958/j.0974-0279.27.1.009

15. Rohith, G. V., Rashmi, K. S., Hamsa, K. R., Lekshmi, U. D., Rajeshwari, D., Manjunatha, A. V., & Olekar, J. (2015). Incorporating the Cost of Irrigation Water in the Currently Underestimated Cost of Cultivation: An Empirical Treatise. *Indian Journal of Agricultural Economics*, 70(902-2016-68388), 319-332. doi: 10.22004/ag.econ.230067.
16. Shelke, R. D., Jadhav, V., & Katkade, J. L. (2016). Comparative Economics of Cost and Returns of Organic Tomato Production with Inorganic Tomato Production in Kolar District of Karnataka. *International Research Journal of Agricultural Economics and Statistics*, 7, 159-163.
17. Singh, D., Biswal, A. K., Samanta, D., Singh, V., Kadry, S., Khan, A., & Nam, Y. (2023). Smart high-yield tomato cultivation: precision irrigation system using the Internet of Things. *Frontiers in Plant Science*, 14, 1239594. doi: 10.3389/fpls.2023.1239594
18. Tesfay, T., Berhane, A., & Gebremariam, M. (2019). Optimizing Irrigation Water and Nitrogen Fertilizer Levels for Tomato Production. *The Open Agriculture Journal*, 13, 198-206. doi: 10.2174/1874331501913010198
19. Traoré, A., Bandaogo, A. A., Savadogo, O. M., Saba, F., Ouédraogo, A. L., Sako, Y., Serme, I., & Ouédraogo, S. (2022). Optimizing Tomato (Solanum lycopersicum L.) Growth With Different Combinations of Organo-Mineral Fertilizers. *Frontiers in Sustainable Food Systems*, 5, 694628. doi: 10.3389/fsufs.2021.694628
20. Wang, X., & Xing, Y. (2017). Evaluation of the effects of irrigation and fertilization on tomato fruit yield and quality: a principal component analysis. *Scientific Reports*, 7(1), 350. https://doi.org/10.1038/s41598-017-00373-8
21. Zhai, Y., Yang, Q., & 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. doi:10.1371/journal.pone.0142204
22. Zhang, H., Xiong, Y., Huang, G., Xu, X., & Huang, Q. (2017). Effects of water stress on processing tomatoes yield, quality, and water use efficiency with plastic-mulched drip irrigation in sandy soil of the Hetao Irrigation District. *Agricultural Water Management*, 179, 205-214. doi: 10.1016/j.agwat.2016.07.022
23. Zhuo, L., & Hoekstra, A. (2017). The effect of different agricultural management practices on irrigation efficiency, water use efficiency, and green and blue water footprint. *Frontiers of Agricultural Science and Engineering*, 4, 185-194. https://doi.org/10.15302/J-FASE-2017149

Figures

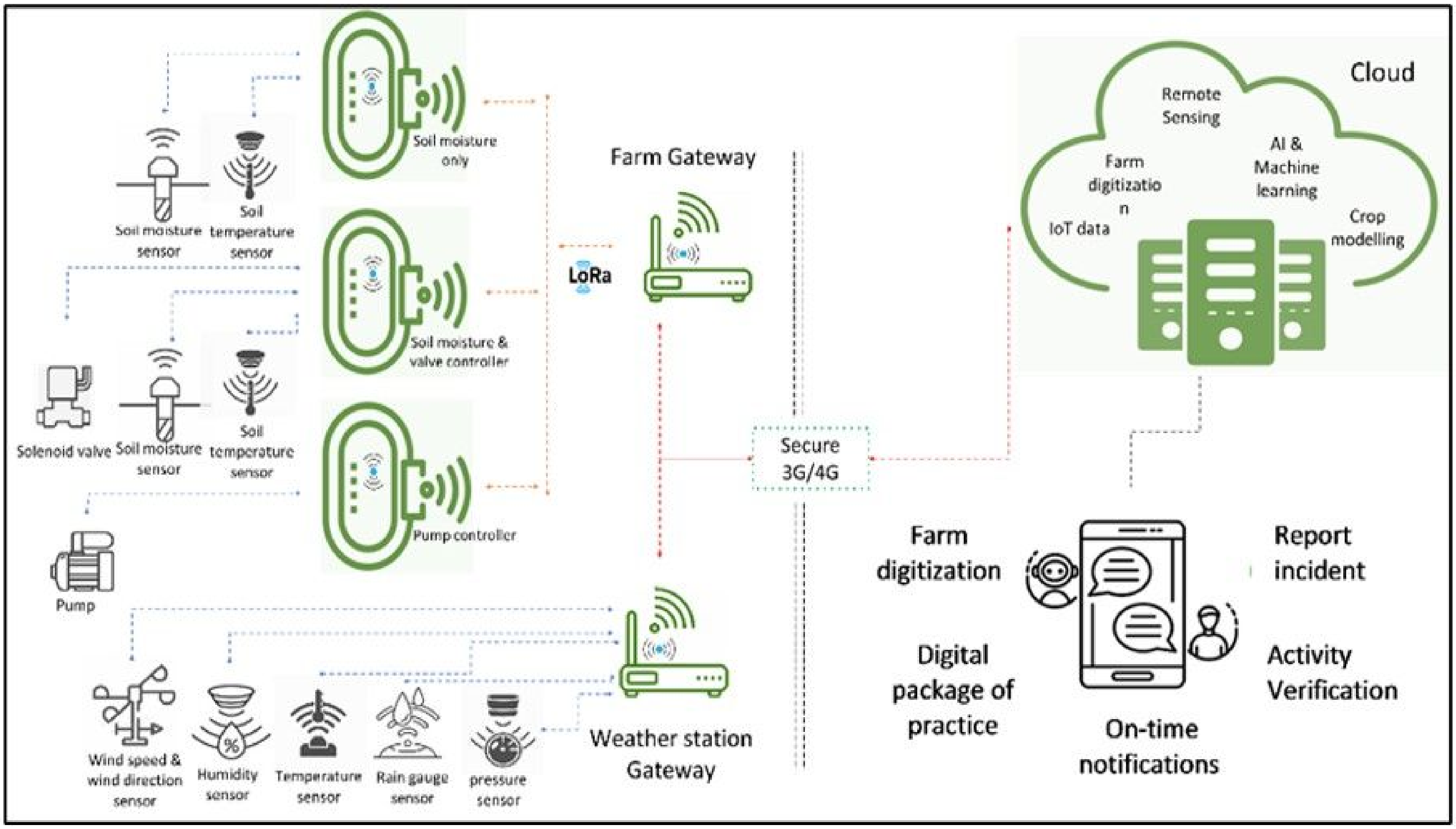


Figure 1

Network architecture for a wireless sensor network and automation system developed by Digite Infotech.

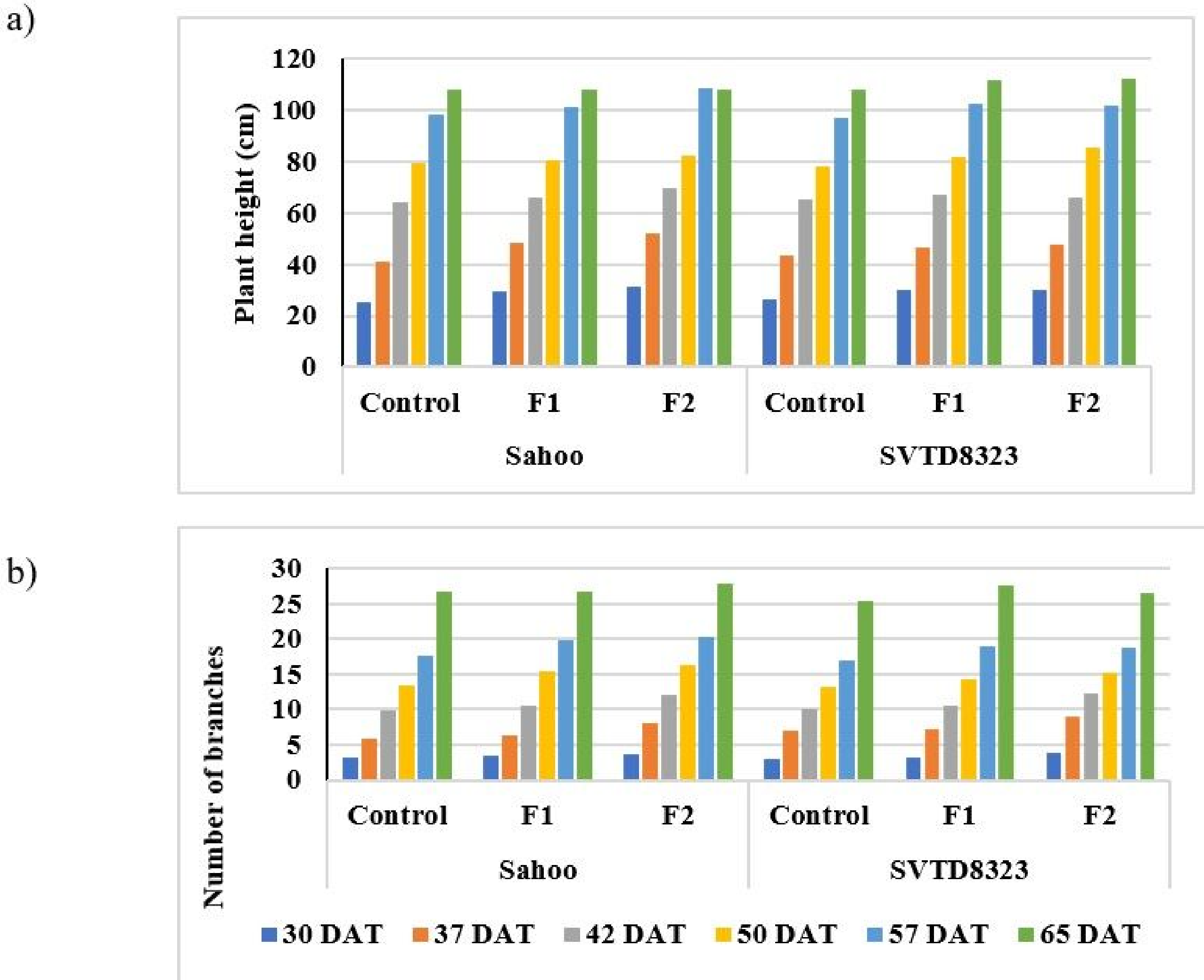


Figure 2

Observation recorded on plant height and number of branches at seven-day intervals. Wherein two varieties Sahoo and SVTD-8323 were observed under F1: 100 % RDF + 50 kPa and F2: 75 % RDF + 50 kPa and control – IIHR RDF + alternate day irrigation.

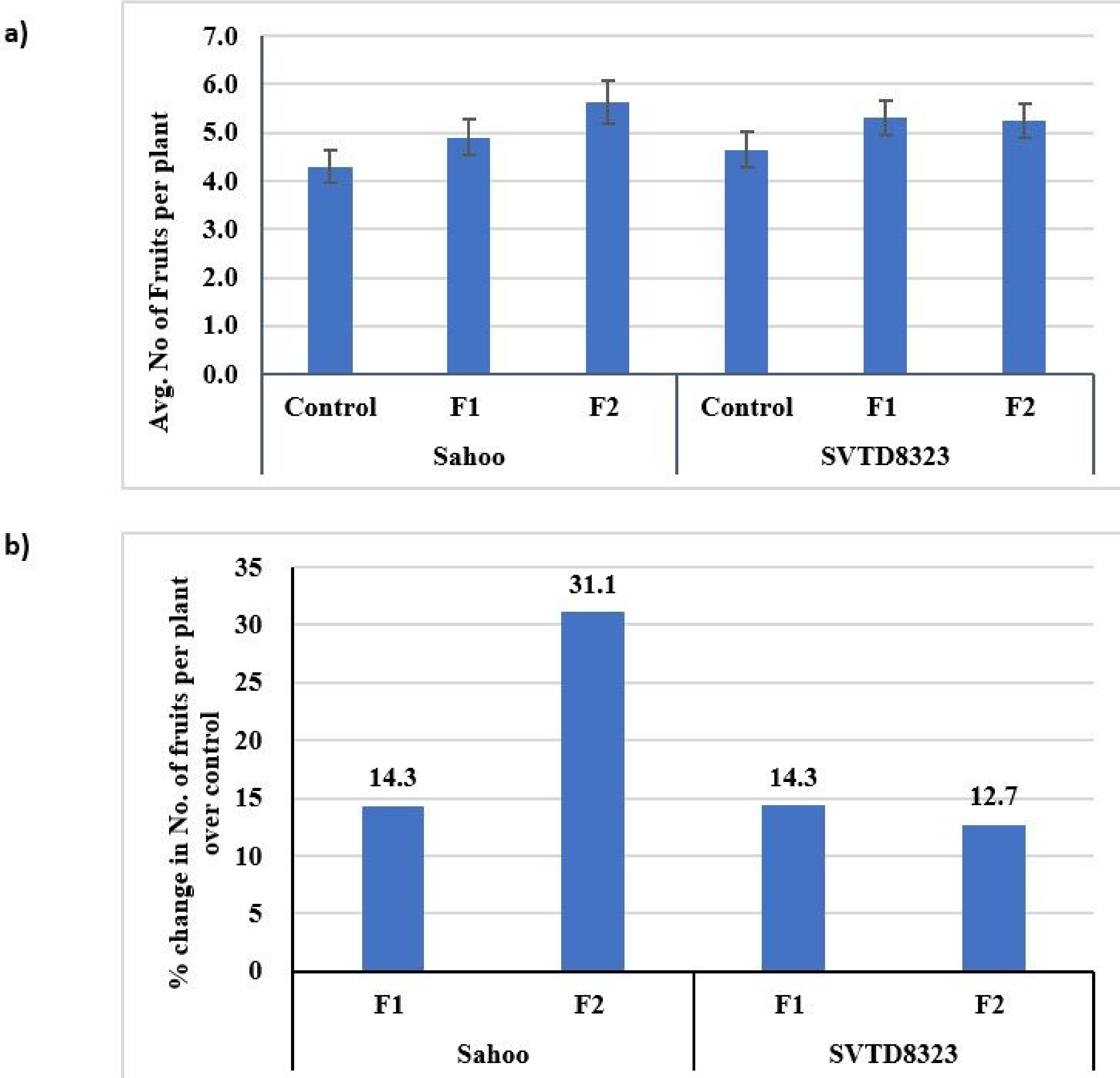


Figure 3

Observations on number of fruits per plant at harvest. a) Average number of fruits harvest per plant b) Per cent change over number of fruits per plant over control. Wherein two varieties Sahoo and SVTD-8323 were observed under F1: 100 % RDF + 50 kPa and F2: 75 % RDF + 50 kPa and control – IIHR RDF + alternate day irrigation.

a)

b)

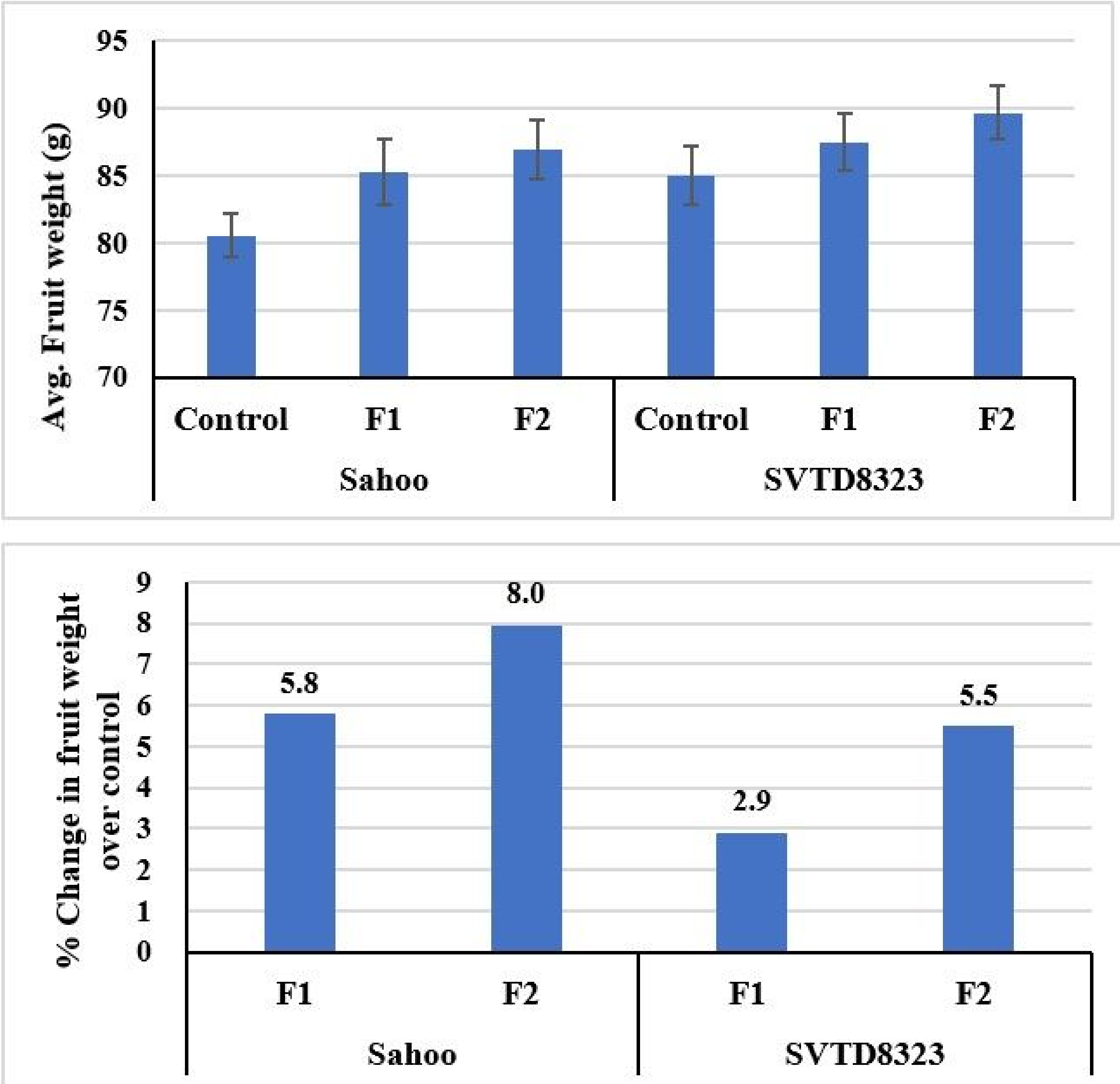
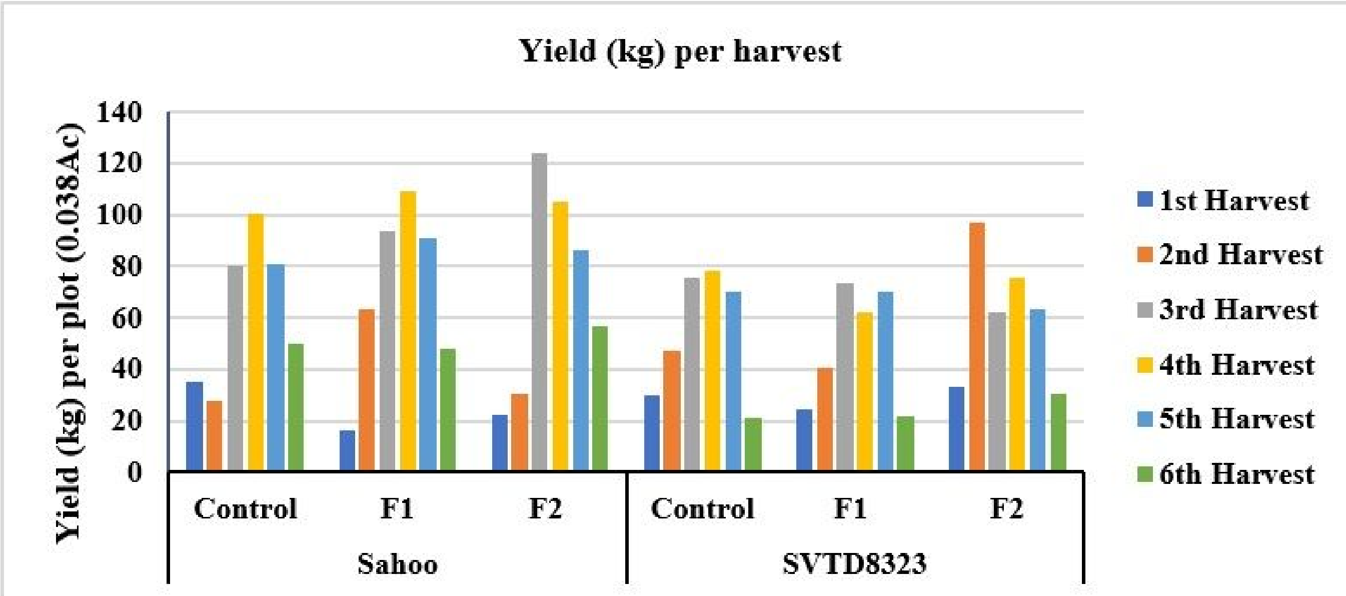


Figure 4

Observation on fruit weight at harvest. a) Average fruit weight of all harvest and b) Per cent change over fruit weight over control fruit weight. Wherein two varieties such as Sahoo and SVTD 8323 observed under F1: 100 % RDF + 33 kPa and F2: 75 % RDF + 33 kPa and control – IIHR RDF + alternate day irrigation.

a)



b)

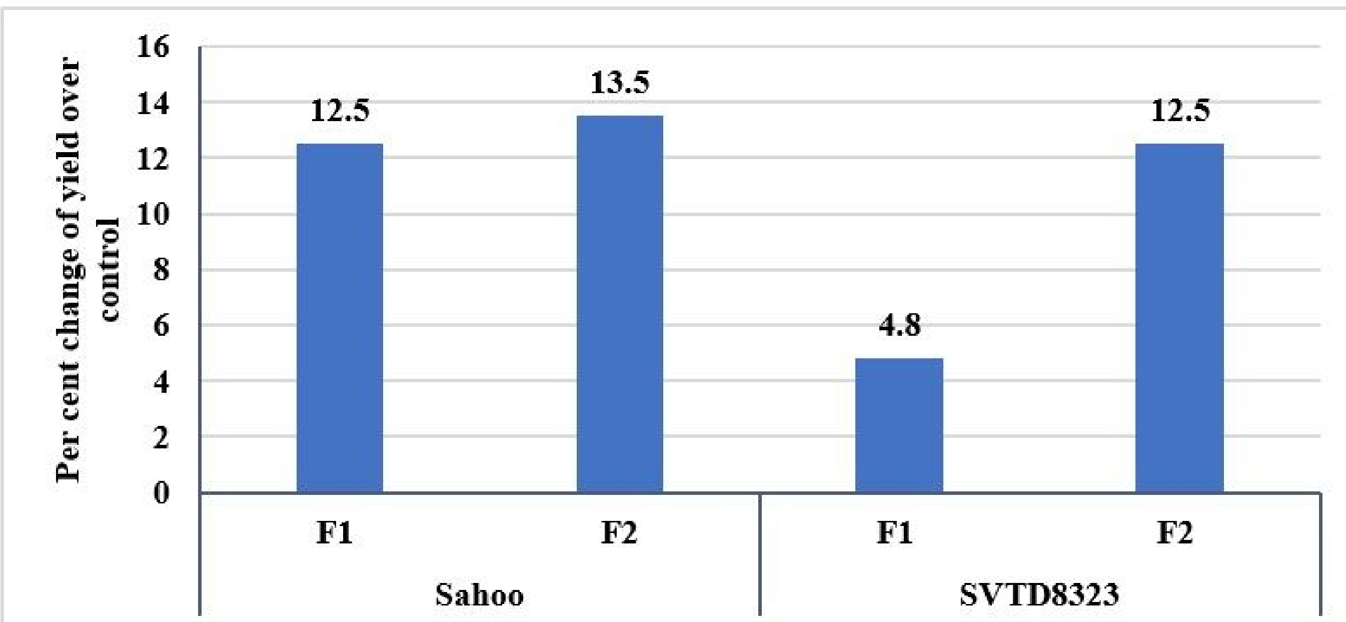


Figure 5

Yield of tomato a) Total yield at each harvest and b) Per cent change of tomato yield over control. Wherein two varieties Sahoo and SVTD 8323 were observed under F1: 100% RDF + 50kPa and F2: 75% RDF + 50kPa and control – IIHR RDF + alternate day irrigation.