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ORIGINAL ARTICLE

Adoption of Sensor-Based Smart Drip Irrigation for Water-Efficient Rooftop Gardening under Labor Constraints in Bangladesh

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Abstract

Rooftop gardening has become popular in many regions of the world, yet its adoption in Bangladesh remains limited due to several challenges. Urban households often avoid rooftop cultivation because of concerns such as over-irrigation causing waterlogging, the structural threat of water accumulation on roofs, and the inconvenience of frequently climbing stairs to water plants. These factors collectively discourage broader participation in rooftop agriculture despite its environmental and socio-economic benefits. To overcome these barriers, this study introduces a sensor-based automatic drip irrigation system designed to optimize water use, reduce manual labor, and ensure safe rooftop gardening. The research evaluated a rain sensor-based automatic drip irrigation system in comparison with customary watering system for tomato (*Solanum lycopersicum L.*) cultivation. The experiment was conducted at Sylhet Agricultural University from November 2024 to January 2025 following a Completely Randomized Design with two treatments: Sensor Based Automatic Drip Irrigation (SI) and Conventional Irrigation (CI) and five replications. The findings showed that the SI system significantly enhanced plant height, flower production, fruit yield, and total output relative to manual irrigation. Water use efficiency improved by 40%, with an overall 25% reduction in water application. Economic analysis showed that SI system was more profitable, with lower production costs (USD 55.10) compared to the CI system (USD 66.18). Overall, the findings indicate that sensor-based smart watering system offer a practical, cost-effective, and water-efficient solution for rooftop gardening in Bangladesh. By addressing limitations of manual irrigation, this technology can promote adoption of sustainable rooftop farming practices across the country.

Keywords: Automated irrigation system, Home gardening, Tomato production, Urban agriculture, Water use efficiency (WUE).

1. Introduction

In Bangladesh and other urban locations across the world, rooftop gardening is becoming more and more popular. Rooftop gardens are growing in popularity as a green solution because they help reduce heat in urban areas, grow vegetables, fruits, herbs in cities where open land is limited and make better use of unused rooftop spaces (Jawad et al. 2022; Koriesh and Abo-Soud 2020). Rooftop gardens also enhance the aesthetic value of the cityscape, adding greenery to concrete structures and creating visually appealing environments (Villalba et al. 2023), plants emit oxygen and absorb carbon dioxide during photosynthesis, helping improve air quality and contributing to a healthier urban atmosphere (Priya and Senthil 2024; Zhang and Kim 2023). A single 1.5 m by 1.5 m section of a grass-planted roof can produce enough oxygen in one year to support the annual respiratory needs of one person.

Rooftop gardening in Dhaka improves mental health, recreation and income (Ashikuzzaman et al. 2025; Chowdhury et al. 2020). Because of limited time and poor soil, its popularity has increased, especially after the COVID-19 pandemic (Chowdhury et al. 2020).

The most important and crucial component for advancing urban rooftop gardening is water. However, the main drawback of this strategy is the crop irrigation method (Gilliom et al. 2019). About 87% rooftops are being used for gardening (Appolloni et al. 2021; Dipannita et al. 2025). Generally, almost 90% of rooftop gardeners used traditional irrigation techniques with their own groundwater source and local traditional instruments like hose pipes and cups. The primary drawbacks of the conventional water application method are that it is labor-intensive, time consuming, wastes a significant amount of valuable water that discourages rooftop gardening (Zaman 2022).

Maintaining a garden has become difficult for many people due to busy schedules and the need for regular plant care. The main challenges faced by rooftop gardeners are limited time, insufficient soil fertility, and the absence of appropriate guidance (Specht and Sanyé-Mengual 2017). Without proper monitoring and timely watering, plant health often declines and the garden's condition suffers (Song 2020). Also excess irrigation and inadequate drainage system of rooftop gardens can cause wetted condition of roofs, which may lead to damage of rooftop.

To overcome the challenges of manual watering and limited time availability, smart irrigation systems using sensors, timers and artificial intelligence have been developed. These systems monitor soil moisture and automate irrigation to provide plants with the right amount of water (Ahmed et al. 2021; Miah et al. 2022). They also help avoid overwatering, which supports healthy growth and reduces both labor and expenses (Askaraliev et al. 2024; Touil et al. 2022). These automated systems also protect rooftop structures from water damage and support efficient water use (Prodhan et al. 2022). Numerous studies indicate that drip irrigation is a better option than other methods for watering rooftop gardens. A drip irrigation system, which delivers water directly to the root zone, can be an effective method for improving irrigation management and water use efficiency in rooftop gardens (Li et al. 2021; Ma et al. 2020). Given the vulnerability of rooftop gardens to extreme weather such as strong winds and direct sunlight, maintaining appropriate soil moisture is essential to prevent plant wilting, reduce crop loss, and ensure sustainable production. Rain sensor enabled automatic irrigation devices further enhance efficiency by stopping irrigation during rainfall and thus preventing waste and root rot (Ishak et al. 2017). Tomato (*Solanum lycopersicum* L.) was selected as the test crop because it is widely grown in rooftop gardens in Bangladesh, well-suited for container-based cultivation, and economically important. It is also sensitive to soil moisture variation, making it an effective indicator crop for evaluating smart irrigation systems, and it is suitable for the growing season during the experiment.

This study evaluated a rain sensor automatic irrigation system that uses a hose pipe-operated drip system, a solenoid valve, a filter, and a programmable digital timer to irrigate rooftop gardens. With this irrigation system, the crop was watered at the selected interval, discharge, and occurrence rate according to a programmable digital timer that sends a signal to the solenoid valve, which opens or shuts the whole irrigation system. For a number of reasons, including minimizing plant root rot and other problems, saving water, lowering expenses, and preventing overwatering by automatically stopping irrigation when it rains, a rain sensor automatic irrigation device is highly advantageous.

2. Materials and Methods

2.1. Study area

The experiment was carried out at Sylhet Agricultural University (SAU), located within the Sylhet metropolitan area of Bangladesh. Geographically, SAU lies at 24°54′ N latitude and 91°53′ E longitude, with an elevation of about 10 meters above sea level (Deb et al. 2013; Singha et al. 2024). The experimental period extended from November 2024 to January 2025. Based on records from the Bangladesh Meteorological Department (BMD), the average temperature in January was approximately 21.9°C, which gradually decreased to 14 °C December. By January, the mean temperature was 13.5°C. A location map of the study area is presented in Fig. 1.

2.2. Experimental design and treatment

A field experiment was carried out using a factorial setup within a Completely Randomized Design (CRD). Two factors were evaluated: (i) Conventional irrigation (CI) and (ii) Sensor-based automatic drip irrigation (SI). Five replications were conducted for the experiment. So, the total number of experimental units was ten.

2.3. Soil preparation

Soils were collected from their respective sources, air-dried, and sieved to remove coarse particles. The physical and chemical characteristics of each soil type were determined prior to planting. Table 1 and Table 2 showing the physical and chemical properties of soil. For soil temperature measurement, a digital soil thermometer was used. Soil texture was determined using the hydrometer method, and soil pH was measured using a digital pH meter.

The concentrations of other chemical components, including total nitrogen, available phosphorus, sulfur, zinc, iron, calcium, magnesium, and potassium, were determined using the spectrophotometric method.

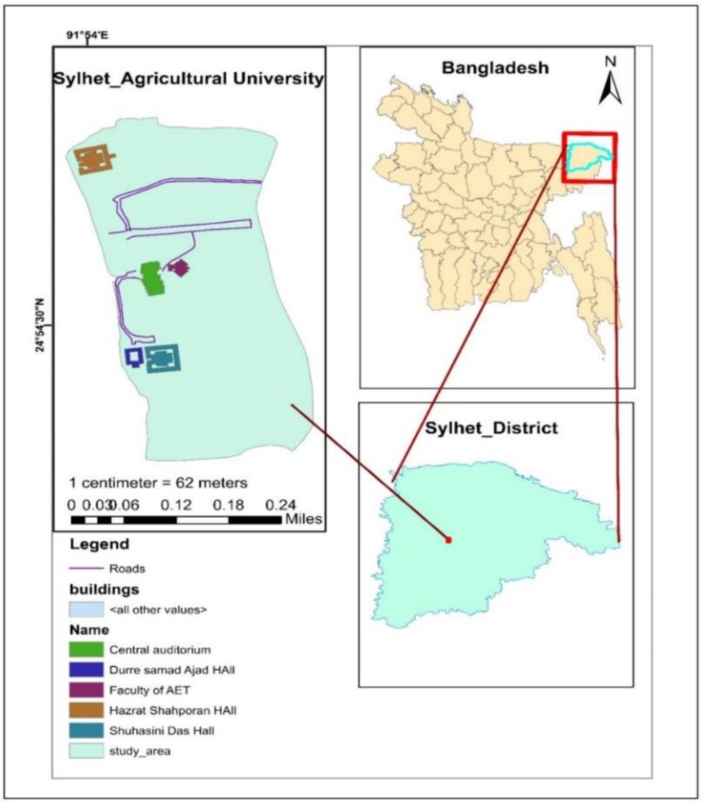

Fig. 1. Location map of study area

Table 1. Physical Properties of Soil.

Temperature	Color	Percentage of Soil Particles			Soil Texture
		Sand (%)	Silt (%)	Clay (%)	
22-25°C	Dark Brown	67.56	22.00	10.44	Sandy Loam

Table 2. Chemical Properties of Soil.

pH	Total N	P	S	Zn	Fe	Ca	Mg	K
	%	µg/g soil (Available)				Meq/100 g soil (Available)		
6.3	0.062	34	1.2	5.55	448.2	3.52	1.19	0.27

Fertilizer applications followed local agronomic recommendations. Soil, cow dung and vermicompost were incorporated at a ratio of 3:2:1 (Soil: Cow dung: Vermicompost), ensuring thorough mixing before planting. A balanced NPK fertilizer (20-20-20) was applied in three equal splits at 15, 30, and 45 days after planting. For this study 19 L volume (Height 30.5 cm, Top diameter 30 cm and bottom diameter 24.5 cm) plastic pots were utilized. Drainage holes were properly created at the bottom of the pot to prevent root rot. After mixing all the ingredients properly the pots were filled with the mixed soil.

2.4. Installation and irrigation setup

A NADSTER rain sensor irrigation timer was used in this experiment and attached to the tank tap using a grooved special water tap. The timer had two ends: one connected to the main supply pipe and the other to the tap. A filtration system was installed to prevent clogging of drippers and other components by impurities in the irrigation water. The irrigation pipe was connected to the universal hose connector at the bottom of the device. A NADSTER (Dia 4/7 series PVC-PN10) pipe was used as the main supply line, while five lateral pipes were connected to supply water to five pots. A NADSTER (Dia 8/12 series PVC-PN10) pipe was used for the lateral lines. Adjustable drippers were fixed to the lateral pipes and positioned near the base of each plant to ensure water supply to the root zone.

2.5. Irrigation scheduling

An automated rain-sensor device was used for irrigation by setting a specific start time and watering duration. The device was connected to a tap attached to a nearby water tank. Irrigation was scheduled at 4:00 PM with a fixed watering duration of 9 minutes on alternate days. The irrigation duration was determined based on the dripper flow rate (2.9 Lhr^{-1}) and crop water requirement of tomato (approximately 600-700 mL per plant). In this study, an average of about 400 mL water per plant was applied under the SI system, while about 500 mL per plant was applied under the CI method. In the CI treatments, water was applied manually every afternoon in a fixed amount to each plant using the traditional method.

2.6. Seed germination and transplanting

Seedbeds were prepared according to the assigned soil and irrigation treatments. Seeds of a standardized BINA-4 Tomato (*Solanum lycopersicum L.*) cultivar were soaked in water for 12 hr, wrapped in a moist cotton cloth, and allowed to germinate. Germinated seeds were transferred to small pots for nursery growth. 30 days-old healthy seedlings were moved to the main pots, maintaining 70 cm between each plot, and were sown at a depth of 2-3 cm (Fig. 2). To mitigate transplant shock, the process occurred in the afternoon. Adequate watering was managed to ensure optimal hydration of the seedlings before transplantation.

Fig. 2. Rooftop experimental layout for pot-grown Tomato cultivation

2.7. Irrigation management

At the beginning of the experiment, the field capacity (FC) of the soil was determined to ensure the application of optimal irrigation levels. Field capacity was determined using the gravimetric (weight-based) method.

Based on the measurements, the field capacity of the soil was found to be 26.41%. To determine the required irrigation under the conventional method, soil moisture was monitored regularly using the gravimetric method. Each pot was weighed daily to find out how much water was lost through evaporation and plant use. The difference between the pot's field capacity weight and its actual weight indicated the amount of water lost, which is the amount of water needed to replenish or maintain the target field capacity. Irrigation was applied every two days to maintain the desired soil moisture for conventional irrigation. For the sensor based automatic drip irrigation, the discharge rate of emitter was calibrated according to the water volume needed to replenish field capacity, and irrigation start time and duration were programmed based on this discharge rate to ensure accurate and consistent water delivery (Fig. 3). The emitter flow rate was calculated by using the following equation:

$$\text{Flow rate (L hr}^{-1}) = \frac{(Volume\ collected(L) \times 60)}{Time\ in\ minutes(\text{min})} \quad (1)$$

The calculated average flow rate of emitters was 2.9 Lhr^{-1}

2.8. Flowering and fruit development

The first flowering occurred 30 days after transplantation and the first fruit was set 38 days after transplanting (Fig. 4). Plant height, stem diameter, the number of blooms and fruits were all monitored during the observation period. The plants were pruned twice to remove surplus vegetation, thereby promoting vigorous growth and better fruit production.

Fig. 3. Components of the automated irrigation system: **(a)** installation layout of the drip emitter, and **(b)** the automatic irrigation controller unit

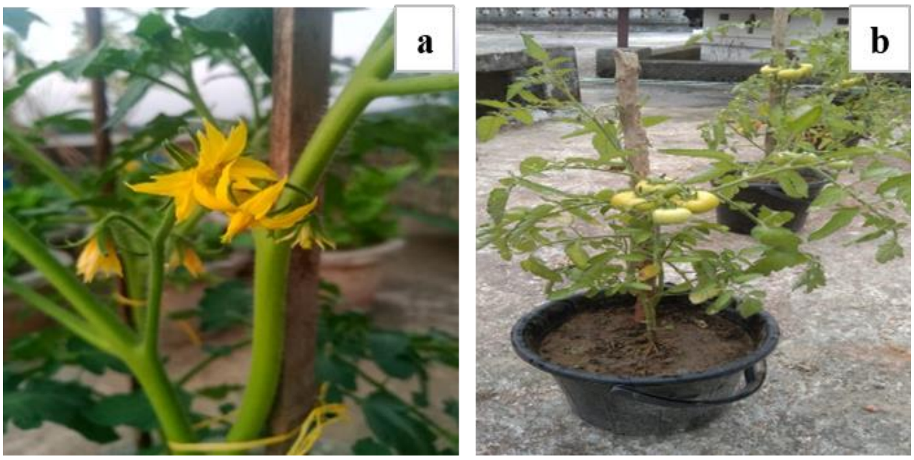

Fig. 4. Tomato plant development showing **(a)** the flowering stage, and **(b)** fruit development

2.9. Crop management

To manage infestations of cutworms and leafhoppers, a solution of Diazinon 60 EC (2 ml per liter) was applied. Staking was performed to support plant structure, ensure proper branch orientation, and facilitate better sunlight interception and fruit development. Weeding was also performed to remove unwanted vegetation.

2.10. Harvesting and data collection

The first harvesting was done 61 days after transplanting. Fruits were harvested as they ripened and attained maturity. Measurements were taken to record the height of the plants, number of flowers, fruit weight, yield, water use efficiency between sensor based automatic drip irrigation and conventional irrigation system.

2.11. Statistical analysis

All data were analyzed using SPSS version 23.0 (SPSS Inc., Chicago, IL, USA). One-way analysis of variance (ANOVA) was used to determine the effects of soil type and irrigation regime. T test was applied to determine the level of significance. Graphs were prepared using OriginPro 2025b (OriginLab Corporation, MA, USA).

2.12. Water Use Efficiency (WUE)

Between the two treatments, in sensor based automatic drip irrigation (SI) the device applied water with the predetermined frequency and amount, for other treatment (CI) manually applied water like farmers' practices. For measuring water use efficiency (WUE) at first water used in each plant was measured. After that the mean value of plant water use was measured. Water use efficiency was measured by using grain yield and total amount of water that was irrigated. Grain yield divided by total irrigation water used throughout the growing season is known as water use efficiency. It was estimated by the following equation:

$$\text{WUE (\%)} = \left[\frac{Dry\ matter\ produced\,(kg)}{Water\ applied\ (kg\ or\ L)}\right] \times 100 \qquad (2)$$

3. Results and Discussion

3.1. Statistical analysis results

Table 3 presents the statistical analysis of yield between sensor-based automatic drip irrigation and conventional irrigation. The statistical analysis showed a significant effect of irrigation regime on tomato yield. The independent t-test revealed a highly significant difference between sensor based automatic drip irrigation and conventional irrigation ($p = 0.0015$), while ANOVA confirmed overall significant variation among treatments ($p < 0.05$), indicating that yield differences were treatment-dependent rather than random. Higher yield under SI can be attributed to improved soil moisture regulation, better nutrient uptake, and reduced water stress.

This agrees with recent studies reporting that drip irrigation enhances tomato productivity by optimizing root-zone conditions and water use efficiency (Mukherjee et al. 2023; Wang et al. 2022). Overall, both statistical tests confirm that irrigation regime significantly influences tomato yield, with drip irrigation consistently outperforming conventional practice.

3.2. Plant height

Figure 5 illustrates the variation in tomato plant height under sensor-based automatic drip irrigation (SI) and conventional irrigation (CI) treatments at different days after transplanting. Plant height was recorded from the top of the root to the tip of the branch. The results from the statistical analysis were consistent with those of other measured parameters, indicating that irrigation method influenced plant height at 15-60 days after transplanting for SI and CI practice was statistically significant ($P < 0.05$) at a field capacity of 26.41%, where different lowercase letters above the bars represented significant differences between treatments. The minimum average plant height was observed 62 cm on CI and 72 cm on SI treatments for 60 days after transplanting. The maximum average plant was observed 76 cm on CI and 94 cm on SI for 60 DAT. Thus, the height of plants for SI increased 10.45% than the conventional system (Fig. 5).

The notable increase in plant height under SI suggests that a steady and well-regulated water supply promotes consistent vegetative growth. At 60 days after transplanting (DAT), plants under SI system reached a height of 94 cm, which was 10.45% greater than those under CI 76 cm. This enhancement is likely due to the precise delivery of water to the root zone, minimizing water stress and enhancing nutrient absorption.

Table 3. Statistical analysis of yield under two treatments.

Parameters	Sensor Based Automatic Drip Irrigation	Conventional Irrigation
Mean	2.86	2.516
Variance	0.01595	0.00393
Number of Observations (n)	5	5
Degrees of Freedom (df)	6	
P(T<=t) two-tail	0.001579207	

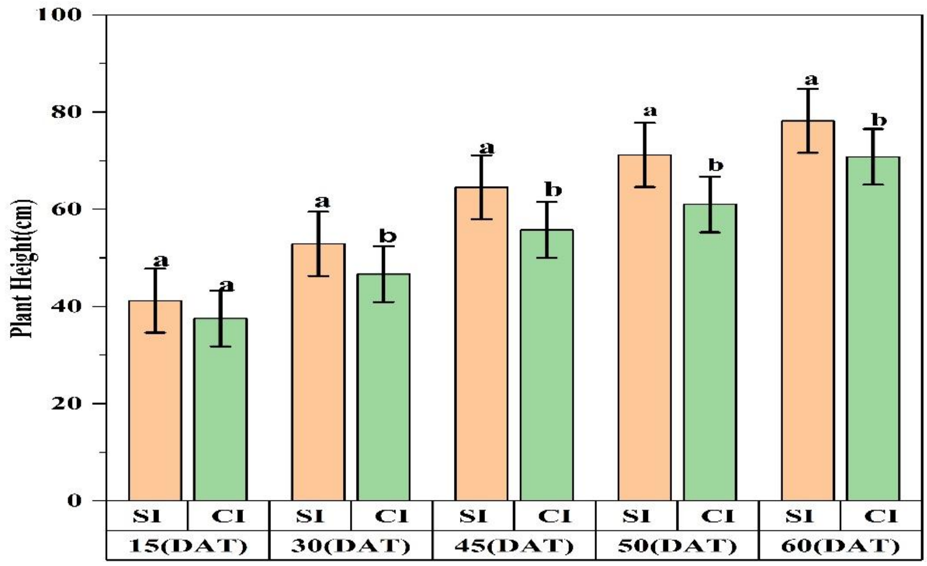

Fig. 5. Variation in tomato plant height at different days after transplanting under Sensor based Automatic Drip Irrigation (SI) and Conventional Irrigation (CI) treatments.

Comparable results were observed by Singh et al. (2023), who reported that regulated irrigation improves root performance and overall plant health. Similarly Yang et al. (2023) demonstrated that, drip irrigation improves crop growth, physiology and quality.

3.3. Number of flowers

The Fig. 6 presents the number of flowers produced per plant under sensor-based automatic drip irrigation (SI) and conventional irrigation (CI) treatments at 50 days after transplanting (DAT). There was a significant effect of controlled amount of water application on plants flowers. At 50 days after transplanting, the number of average flowers for SI was 24.8 and the number of average flowers for CI was 16.2.

The number of flowers per plant for automatic drip irrigation was more than the farmer's practice. It was statistically significant (P< 0.05), bars with different lowercase letters indicated significant differences and error bars represented standard error (SE). As shown in Table 4 the flowers of plants for SI were 53.08% more than the CI. A difference of average number of flowers between two treatments shown in Fig. 6.

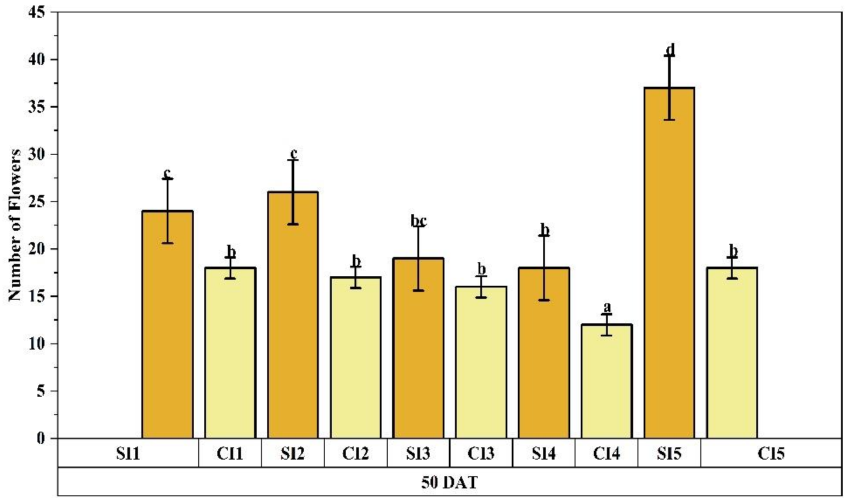

Fig. 6. Effects of water application on number of flowers in two treatments at 50 DAT. SI1-SI5 denote the five replications of the sensor-based automatic drip irrigation treatment; CI1-CI5 denote the five replications of the conventional irrigation treatment. Vertical bars represent the mean value ± standard error.

The number of flowers per plant was markedly higher under SI compared to conventional irrigation (CI). Plants receiving controlled water supply produced 53.08% more flowers, indicating that maintaining optimal soil moisture promotes reproductive development and enhances flower initiation and fruit set. In contrast, irregular moisture levels in conventional irrigation likely led to soil water fluctuations, adversely impacting flowering, and pollination.

This result is similar to a recent study by Elhindi et al. (2016) which found that, the combination of drip irrigation (especially subsurface) and nitrogen fertigation enhanced flowering, along with overall growth and nutrient uptake of zinnia (*Zinnia elegans*). Another study by Kabir et al. (2021), also reported that drip irrigation supports improved physiological processes such as photosynthesis and transpiration regulation.

3.4. Fruits weight

The Fig. 7 shows the mean fruit weight per plant under sensor-based automatic drip irrigation (SI) and conventional irrigation (CI) treatments. The comparison of the data obtained from two treatment showed that the average fruits weight of 5 replication was 2.86 kg for SI practice and 2.516 kg CI practice. The minimum weight of fruits for SI treatment of one plant was 2.70 kg and maximum were 3.00 kg. The minimum weight of fruits CI of plant was 2.45 kg and maximum weight was 2.60 kg (Fig. 7). Different lowercase letters placed above the bars indicate statistically significant differences at ($P < 0.05$). SI practice considerably enhanced fruit output in response to other method.

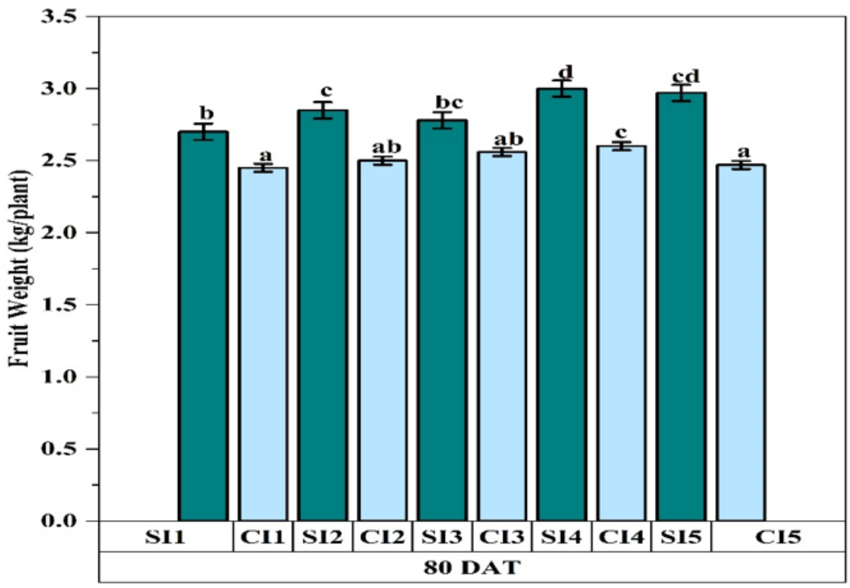

Fig. 7. Mean fruit weight per plant under different water application treatments; data represents cumulative yield across three harvests up to 80 DAT. SI1-SI5 denote the five replications of the sensor-based automatic drip irrigation treatment; CI1-CI5 denote the five replications of the conventional irrigation treatment. Vertical bars represent the mean value ± standard error.

3.5. Yield

Figure 8 presents the effect of irrigation method on tomato yield under sensor-based automatic drip irrigation (SI) and conventional irrigation (CI) treatments, while the yield data are summarized in Table 4. Irrigation water has significant effects on plants yield. Yield varied between the two treatments. As number of flowers and plant height increased under the SI, yield also increased. Total yield from SI treatment for plant was 14.3 kg and total yield for CI treatment was 12.58 kg. The yield from the automatic smart irrigation method was 13.67% higher than that from the conventional method. Which indicate that using more water does not necessarily mean a higher yield. Yield difference between two treatments shown in Fig. 8.

Fruit weight and total yield further confirmed the superiority of the sensor based automatic drip irrigation system. The average fruit weight per plant under SI was 2.86 kg compared to 2.516 kg under conventional irrigation. Similarly, total yield increased by

13.67%, demonstrating that steady water availability during the critical growth and fruit development stages leads to larger and healthier fruits. These results are consistent with the findings of Mukherjee et al. (2023), who observed increased yield in tomato crops under controlled irrigation due to enhanced nutrient uptake and reduced waterlogging stress. This results also aligns with the study by Wang et al. (2022), who reported that sub surface drip irrigation increased fruit production of about 3.37% compare to other method.

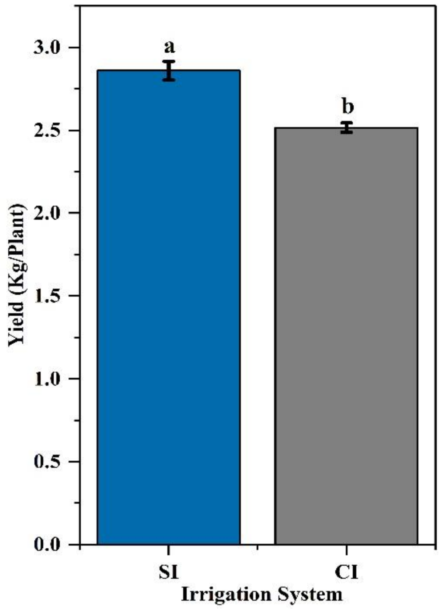

Fig. 8. Effect of irrigation method on tomato yield under Sensor-based Automatic Drip Irrigation (SI) and Conventional Irrigation (CI).

3.6. Water use efficiency

Table 4 summarizes the yield, water use, and water use efficiency (WUE) under SI and CI treatments. The water use efficiency for SI treatment was 0.59% and for CI treatment WUE was 0.42%. Water use efficiency was significantly affected by irrigation treatment ($P < 0.05$). The conventional irrigation method used 25% more water than SI. The amount of excess water applied in CI was determined by comparing the total water applied under two treatments. SI system applied an average of 0.4 liters of water per plant per day to five plants over 59 days, resulting in a total water use of 24 liters. In contrast, the CI method applied slightly more water 0.5 liters per plant per day for the same number of plants and duration amounting to 30 liters in total.

The difference between the two methods shows that conventional irrigation required 6 liters more water than SI, indicating that SI is more water-efficient.

Water use efficiency (WUE) was markedly improved in the SI treatment, which used 25% less water than CI. The WUE under SI was 0.59%, whereas under conventional irrigation it was only 0.42%. The higher WUE indicates that SI system not only saved water but also produced higher yield per unit of water applied. The result has similarity with Singh et al. (2022), who strongly suggest that sub surface drip irrigation improve WUE. According to Alharbi et al. (2024), smart irrigation including drip or variable rate irrigation can significantly improve water use efficiency.

3.7. Cost and return comparison between sensor based automatic drip irrigation and conventional irrigation

Table 5 and Table 6 present the cost components and economic returns of sensor-based automatic drip irrigation (SI) and conventional irrigation (CI) treatments. The economic performance of the two irrigation treatments was evaluated by comparing the total production costs, labor requirements, gross returns, and net returns from tomato cultivation. The SI system reduced labor requirements through automated irrigation scheduling, which contributed to lower operational costs and improved resource-use efficiency.

Therefore, a cost and return analysis was conducted to determine the economic feasibility and profitability of SI compared with the conventional irrigation method. The total investment and economic returns of two treatments determined which method is more profitable and efficient. The process involves calculating all associated costs including devices, materials, labor, soil, seedlings, and pesticides (Table 5) and comparing them with the revenue generated from tomato yield (Table 6). Although the initial investment for SI system was relatively high due to equipment and installation costs, long-term analysis revealed that it is economically advantageous.

The system operated efficiently over extended periods without additional labor expenses for watering. In contrast, conventional irrigation methods incurred ongoing costs for labor and materials. The cost-benefit analysis further strengthens the case for adopting SI. The total cost of SI (USD $55.10) was notably lower than CI (USD $66.02), mainly due to the reduced labor and water requirements. Moreover, the income generated from SI USD $9.34) exceeded that of the CI method USD $8.22).

These results are consistent with the study conducted by Baranchuluun et al. (2014), who compares drip, sprinkler, and furrow irrigation for potatoes, radish, cabbage, and tomatoes using cost-benefit analysis. Results show that drip irrigation is a water and labor-saving alternative to conventional methods. The economic advantage, combined with improved yield and water savings, demonstrates that smart drip irrigation is not only agronomically superior but also financially viable for small-scale farmers. These results align with global evidence suggesting that smart irrigation technologies improve profitability by reducing input costs and enhancing output.

Table 4. Comparison of yield, water use, and water-use efficiency (WUE) under Sensor based automatic drip irrigation (SI) and conventional irrigation (CI).

Factors	Number of fruits per plant	Yield (kg/plant)	Total Yield (kg)	Water use (m^3/plant)	Total water use (m^3)	WUE (kg/m^3)
Smart Drip Irrigation	24.8	2.86	14.3	0.024	0.12	0.59%
Conventional Method	16.2	2.52	12.58	0.03	0.15	0.42%

Table 5. Cost Breakdown of Drip Irrigation and Conventional Irrigation Method

Types of Irrigation	Category	Item Description	Amount (USD $)
Sensor Based Automatic Drip Irrigation	Device and related materials	NADSTER rain sensor device	28.52
		Dia 4/7 (70ft) and 8/12 (10ft) PVC-PN10 pipe.	4.40
		Adjustable Dripper (5 piece)	0.24
		Tee Connector (5 piece)	0.33
		Pot (19 litre)	12.22
		Water tap	2.04
	Initial setup	Labor cost	3.67
	Soil and seedlings	Soil	2.04
		Seedlings	1.22
	Pesticides	Diazinon 60EC	0.42
	Total cost for SI	=	55.10
Conventional Irrigation	Materials	Pot (19 litre)	12.22
		Soil	1.63
		Seedlings	1.22
	Pesticides	Diazinon 60EC	0.42
	Labor	Labor cost for initial setup (USD $ 6.50 per day)	2.44
		Labor cost for watering plant (USD $ 0.813 per hour in a day, for 59 days)	48.19
	Total cost for CI	=	66.18

Table 6. Economic Return from Two Method

Irrigation Type	Item	Price per Kg	NO. of Plants	Total Yield (kg)	Amount (USD $)
Sensor Based Automatic Drip Irrigation	Tomato	0.65	5	14.3	9.34
Conventional Irrigation	Tomato	0.65	5	12.58	8.22

Overall, the study concludes that SI significantly improves plant growth, flower formation, fruit weight, yield, and WUE while simultaneously lowering production costs. Unlike conventional irrigation, which relies on frequent manual watering and often leads to water excess or deficit, SI ensures precise, uniform, and timely water delivery that helps reducing waterlogging, promoting healthier and more productive plants. These findings underscore the potential SI systems as a sustainable, resource-efficient, and economically advantageous technology for tomato cultivation, particularly in regions facing water scarcity and rising labor costs.

Future research could explore long-term field trials, on refining irrigation scheduling, integrating nutrient delivery through fertigation, and assessing system performance across varying soil types and climatic conditions to maximize productivity and sustainability.

4. Conclusion

This study confirms that a sensor-based automatic drip irrigation (SI) system is highly effective for rooftop vegetable production. The system enhances crop growth and productivity while improving irrigation efficiency under the constraints of rooftop environments, where water availability, space, and labor are limited. Compared with conventional irrigation (CI) practices, the proposed system enables precise and controlled water application, which not only improves resource use efficiency but also helps reduce waterlogging conditions in rooftop cultivation systems, thereby contributing to better root health and structural safety. Although the initial investment cost is comparatively higher, the system contributes to improved long-term economic performance by reducing operational costs associated with labor and minimizing water losses. Overall, the findings demonstrate that sensor-based drip irrigation is a sustainable and efficient irrigation strategy for rooftop tomato cultivation, with strong potential to support urban agriculture through improved productivity, resource conservation, and reduced waterlogging risk. Future research can focus on integrating renewable energy sources such as solar-powered operation, incorporation of fertigation systems for simultaneous nutrient delivery, and development of intelligent irrigation scheduling algorithms to further enhance system efficiency, adaptability, and scalability in urban rooftop farming systems.

5. Acknowledgements

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6. Conflict of Interest

The authors declare no conflict of interest over this paper.

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