

P-ISSN: 2706-7483
E-ISSN: 2706-7491
 NAAS Rating (2026): 4.5
 IJGGE 2026; 8(4): 38-42
www.geojournal.net
 Received: 12-01-2026
 Accepted: 14-02-2026

Vedantam Sai Krishna
 Assistant Professor,
 Department of Agricultural
 Engineering, Aditya
 University, Surampalem,
 Andhra Pradesh, India

Gayam Sujatha
 Assistant Professor,
 Department of Agricultural
 Engineering, Aditya
 University, Surampalem,
 Andhra Pradesh, India

B Kusumasri
 Research Scholar, Department
 of Agricultural Engineering,
 Aditya University,
 Surampalem, Andhra Pradesh,
 India

Ch Sri Hari Priya
 Research Scholar, Department
 of Agricultural Engineering,
 Aditya University,
 Surampalem, Andhra Pradesh,
 India

K Nagatarun
 Research Scholar, Department
 of Agricultural Engineering,
 Aditya University,
 Surampalem, Andhra Pradesh,
 India

M Sandhya Rani
 Research Scholar, Department
 of Agricultural Engineering,
 Aditya University,
 Surampalem, Andhra Pradesh,
 India

S Keerthana
 Research Scholar, Department
 of Agricultural Engineering,
 Aditya University,
 Surampalem, Andhra Pradesh,
 India

Corresponding Author:
Vedantam Sai Krishna
 Assistant Professor,
 Department of Agricultural
 Engineering, Aditya
 University, Surampalem,
 Andhra Pradesh, India

Development and evaluation of a solar-powered sensor-based automated drip irrigation system for tomato crop

Vedantam Sai Krishna, Gayam Sujatha, B Kusumasri, Ch Sri Hari Priya, K Nagatarun, M Sandhya Rani and S Keerthana

DOI: <https://www.doi.org/10.22271/27067483.2026.v8.i4a.509>

Abstract

Water scarcity and the need for sustainable agricultural practices have driven the development of efficient irrigation systems. This study presents the development and field evaluation of a solar-powered automated drip irrigation system integrated with soil moisture sensors and environmental monitoring capabilities. The system was designed to optimize water usage while maintaining crop productivity through precision irrigation scheduling. The automated system consists of a solar photovoltaic panel, microcontroller-based control unit, soil moisture sensors, and a drip irrigation network. Field trials were conducted to evaluate the system's performance in terms of water use efficiency, crop yield, energy consumption, and cost-effectiveness. Results demonstrated that the automated system achieved significant water savings compared to conventional irrigation methods while maintaining comparable crop yields. The economic analysis revealed favorable payback periods and operational cost reductions. This solar-powered automated irrigation system offers a sustainable solution for precision agriculture, particularly in regions with limited access to grid electricity and water resources.

Keywords: Automated irrigation, Drip irrigation, Solar power, Soil moisture sensors, Precision agriculture, Water use efficiency, Sustainable agriculture

1. Introduction

Agriculture is the largest consumer of fresh water resources globally, accounting for approximately 70% of total water withdrawals^[1]. With increasing population pressure, climate change, and declining water availability, there is an urgent need to develop water-efficient irrigation technologies that can sustain agricultural productivity while minimizing environmental impacts^[2]. Traditional irrigation methods, such as flood and furrow irrigation, often result in significant water losses through evaporation, deep percolation, and surface runoff, with typical application efficiencies ranging from 40-60%^[3].

Drip irrigation has emerged as one of the most efficient irrigation methods, delivering water directly to the root zone of plants through a network of pipes, valves, and emitters^[4]. Studies have shown that drip irrigation can achieve application efficiencies exceeding 90%, resulting in water savings of 30-70% compared to conventional methods^[5, 16]. However, the effectiveness of drip irrigation systems depends largely on proper scheduling and management, which requires regular monitoring of soil moisture conditions and crop water requirements^[6].

The integration of automation and sensor technologies with drip irrigation systems offers significant potentials for further improving water use efficiency and reducing labor requirements^[7]. Automated irrigation systems can monitor soil moisture levels in real-time and adjust irrigation schedules dynamically based on actual crop needs, eliminating the guesswork associated with manual irrigation management^[8]. Recent advances in microcontroller technology, wireless sensor networks, and Internet of Things (IoT) platforms have made it increasingly feasible to develop cost-effective automated irrigation systems for smallholder farmers^[9].

Solar photovoltaic (PV) technology provides an attractive power source for automated irrigation systems, particularly in remote agricultural areas where grid electricity is

unreliable or unavailable ^[10]. Solar-powered irrigation systems can operate independently of the electrical grid, reducing operational costs and carbon emissions while providing a sustainable energy solution ^[11]. The declining costs of solar PV panels and advances in battery storage technology have further improved the economic viability of solar-powered agricultural applications ^[12].

Despite the potential benefits, the adoption of automated drip irrigation systems remains limited, particularly among smallholder farmers in developing countries. Key barriers include high initial investment costs, lack of technical knowledge, and limited access to appropriate technologies ^[13]. There is a need of affordable, user-friendly automated irrigation systems that can be easily installed and maintained by farmers with minimal technical expertise.

2. Methodology

The automated drip irrigation system was designed to operate autonomously using solar power and soil moisture feedback. The system architecture consists of the following main components:

2.1 Solar Power System

A polycrystalline solar panel with 100W capacity and 12V output was selected to power the system. The panel dimensions were 1200mm×540mm×35mm. A 12V/24V PWM solar charge controller (20A capacity) was used to regulate the charging of the battery and prevent overcharging. A 12V, 100Ah deep-cycle lead-acid battery was used to store solar energy and ensure continuous operation during night time and cloudy conditions.

2.2 Control System

An Arduino Mega 2560 microcontroller board was selected as the central processing unit due to its multiple analogs and digital I/O pins, ease of programming, and low cost. Capacitive soil moisture sensors (operating range: 0-100% volumetric water content) were deployed at multiple locations in the field to monitor soil water status. These sensors were preferred over resistive sensors due to their

better durability and resistance to corrosion. A DHT22 digital sensor was integrated to monitor ambient temperature and relative humidity for reference evapotranspiration estimation. A DS3231 RTC module was incorporated to maintain accurate timekeeping for irrigation scheduling. A 20x4 Character LCD display with I2C interface was used to show system status, sensor readings, and operational parameters.

2.3 Irrigation Components

A 12V DC submersible pump with a flow rate of 4L/min and maximum head of 8m was used to deliver water from the source to the drip irrigation network. A 12V DC normally-closed solenoid valve was installed to control water flow to different irrigation zones. Inline drip tubing with 16mm diameter and emitter spacing of 30 cm was used, with each emitter having a discharge rate of 2L/h at 1 bar pressure. A 120-mesh screen filter was installed at the pump outlet to prevent clogging of emitters. Appropriate pipes, connectors, and fittings were used to assemble the irrigation network.

2.4 Experimental Setup

The field experiment was conducted during the growing season at the experimental farm of agriculture field, Aditya University, Surampalem. The climate of the region is characterized as hot and dry weather, with an average annual rainfall of 1040 mm and mean temperature ranging from 24 °C to 34 °C. The soil texture was classified as Sandy loam soils with the following properties as shown in the Table 1.

Table 1: Soil Properties of the sandy loam soil

Sl. No.	Soil Properties	Readings
1	Bulk density	1.48 g/cm ³
2	Field capacity:	25% by volume
3	Permanent wilting point	12% by volume
4	Available water capacity	130 mm/m
5	pH	6.8-7.0
6	Organic matter content:	0.8%



Plate 1: Sensors fixing.



Plate 2: Installation of solar panel

2.5 Experimental Design

A randomized complete block design (RCBD) with three replications was used to compare the performance of the automated drip irrigation system with conventional irrigation practices. The treatments were; (i) T1: Automated

drip irrigation with soil moisture sensors (Automated-DI), (ii) T2: Manual drip irrigation based on farmer's experience (Manual-DI), (iii) T3: Conventional furrow irrigation (Control). Each experimental plot measured 19 m × 8 m, with appropriate buffer zones between plots to prevent

lateral water movement. The test crop was tomato, planted at a spacing of 1 m × 0.7 m.

3. Data Collection and Measurements

3.1 Irrigation Water Applied

The volume of water applied in each irrigation event was measured using a water meter installed in the irrigation line for the automated and manual drip irrigation treatments. For furrow irrigation, water application was measured using a calibrated flow meter at the field inlet. Soil moisture content was monitored continuously in the automated treatment using the installed sensors. For the other treatments, gravimetric soil sampling was conducted weekly to determine soil water content at different depths.

3.2 Crop Growth and Yield Parameters

The following crop parameters were measured; (i) Plant height (measured weekly from 5 randomly selected plants per plot), (ii) Leaf area index (LAI) using a plant canopy analyzer (iii) Biomass accumulation (sampled at different growth stages), (iv) Final crop yield (measured at harvest from the net plot area).

3.3 Water Use Efficiency

Water use efficiency (WUE) was calculated using the following equation:

$$WUE = \frac{Y}{W}$$

(1)

Where Y is the crop yield (kg/ha) and W is the total water applied (mm or m³/ha).
Irrigation water use efficiency (IWUE) was calculated as:

$$IWUE = \frac{Y}{W} \times I$$

(2)

Where I is the irrigation water applied (mm or m³/ha)

3.4 Energy Consumption

The energy consumption of the solar-powered automated system was monitored using a power meter connected between the battery and the load. Daily energy consumption was recorded, and the solar panel’s energy generation was also measured.

3.5 Economic Analysis

A comprehensive cost–benefit analysis was conducted to assess the economic viability of the automated drip irrigation system by considering initial investment costs, operational expenses, and key economic indicators. The initial investment included all capital expenditures such as the solar panel with mounting structure, battery and charge controller, microcontroller and sensors, pump and solenoid valves, drip irrigation components (pipes, emitters, and filters), as well as installation and commissioning costs. Annual operational and maintenance costs were also estimated, covering maintenance and repairs, periodic battery replacement (with a lifespan of 3–5 years), sensor calibration and replacement, and routine filter cleaning and emitter replacement. To evaluate financial feasibility, economic indicators including Net Present Value (NPV) calculated at a 10% discount rate over a 15-year project lifespan, Benefit–Cost Ratio (BCR), Payback Period, and Internal Rate of Return (IRR) were determined.



Plate. 3 Battery

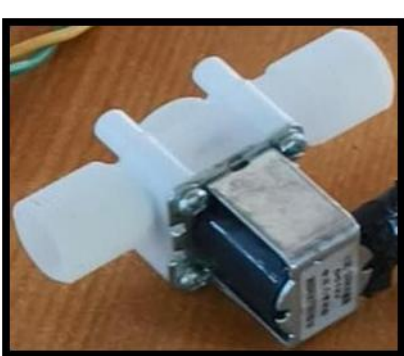


Plate. 4 Solenoid valve



Plate. 5 Drip irrigation

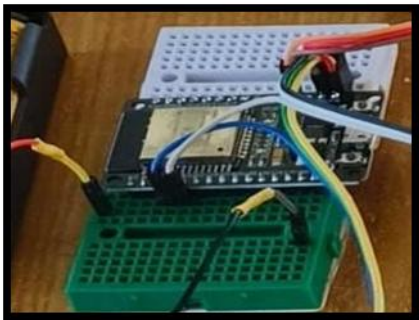
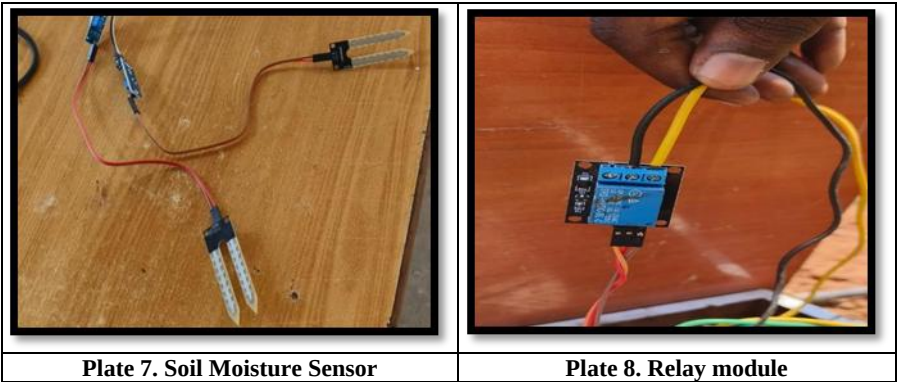


Plate. 6 Microcontroller



3.6 Statistical Analysis: Data were analyzed using analysis of variance (ANOVA) to determine significant differences among treatments. Mean separation was performed using Tukey’s HSD test at 5% significance level. Statistical analysis was performed using [Design Expert software 13].

4. Results and Discussion

The automated drip irrigation system operated successfully throughout the growing season with minimal technical issues. The solar power system provided adequate energy for continuous operation, with the battery maintaining sufficient charge even during consecutive cloudy days. The average daily energy generation from the 100W solar panel was 0.38 kWh/day, while the average daily energy consumption of the automated system was 0.32 kWh/day. The battery storage capacity was sufficient to maintain system operation for up to 2-3 days without solar charging,

providing a safety margin for extended cloudy periods. The soil moisture sensors demonstrated good accuracy when compared with gravimetric measurements, with a mean absolute error of 4.5% and R² value of 0.91. The sensors maintained stable performance throughout the season with minimal drift or calibration issues.

4.1 Irrigation Water Application

The automated drip irrigation system applied significantly less water (420 mm) compared to manual drip irrigation (510 mm) and furrow irrigation (720 mm), representing water savings of 18% and 42%, respectively. The automated system achieved these savings by precisely matching water application to crop requirements based on real-time soil moisture feedback. The total water applied and the number of irrigation events for each treatment during the growing season is given in Table 2.

Table 2: Irrigation water application for different treatments

Treatment	Total Water (mm)	No. of Events	Water Saved (%)
Automated-DI	420±25	38	-
Manual-DI	510±30	30	17.6%
Furrow Irrigation	720±40	12	41.7%

The temporal variation of soil moisture content in the root zone for different irrigation treatments is given in Fig. 1. The automated system-maintained soil moisture within the

optimal range (between field capacity and management allowed depletion) more consistently than the other treatments.

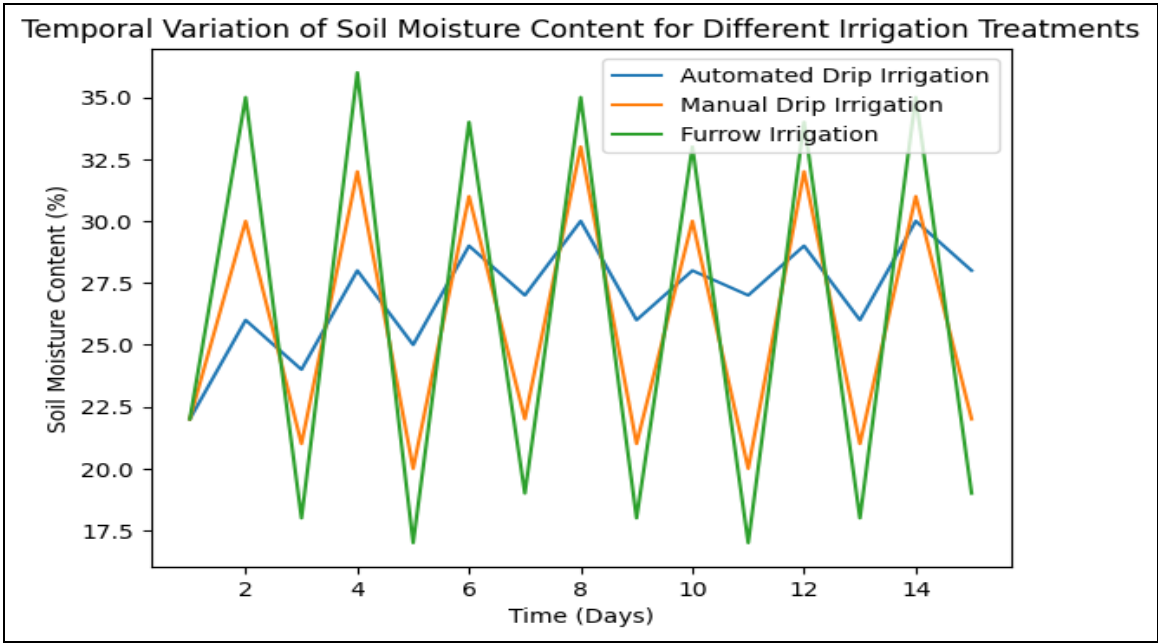


Fig. 1: Soil Moisture Dynamics

4.2 Crop Growth and Development: Plant height increased progressively throughout the growing season in all treatments, with no significant differences observed between the automated and manual drip irrigation treatments at most growth stages. However, furrow irrigation showed slightly reduced plant height during the mid-season due to water stress periods between irrigation events.

The leaf area index (LAI) reached maximum values of 4.2, 3.8, and 3.1 for automated DI, manual-DI, and furrow irrigation treatments, respectively. The automated treatment

maintained higher LAI values during critical growth stages, indicating better plant water status. Table 3 depicts the crop yield and quality parameters for different irrigation treatments. The automated drip irrigation system achieved a crop yield of 62500 kg/ha, which was statistically similar to manual drip irrigation (58400 kg/ha) but significantly higher than furrow irrigation (45600 kg/ha). the yield increase in drip irrigation treatments was attributed to better water management and reduced water stress during critical growth stages.

Table 3: Crop yield and quality parameters for different treatments

Parameter	Automated-DI	Manual-DI	Furrow Irrigation
Yield (kg/ha)	62500 ± 3200	58400 ± 2950	45600 ± 3100
Marketable yield (%)	91.5 ± 2.4	88.2 ± 2.8	76.3 ± 3.5
Quality parameter	5.8 ± 0.4	5.5 ± 0.5	4.7 ± 0.6

Note: Values followed by different superscript letters are significantly different at $p < 0.05$

The automated drip irrigation system achieved the highest water use efficiency (14.8 kg/m³), representing improvements of 29% and 57% over manual drip irrigation and furrow irrigation, respectively. This improvement was primarily due to the reduced water application while maintaining comparable yields. Water use efficiency metrics for different irrigation treatments are presented in Table 4.

The automated drip irrigation system demonstrated significant water savings while maintaining crop productivity, consistent with findings from previous studies on sensor-based irrigation management^[7, 17]. The 42% water savings achieved compared to conventional furrow irrigation align with reported ranges of 30-70% for drip

irrigation systems^[5]. The additional 18% savings compared to manual drip irrigation highlight the value of automated, sensor based scheduling in eliminating over-irrigation and improving precision.

The ability to maintain soil moisture within optimal ranges throughout the growing season prevented both water stress and waterlogging conditions, which are common issues with fixed schedule irrigation. This precise water management contributed to the observed improvements in water use efficiency and crop quality. Similar benefits of automated irrigation systems have been reported in various crops, including vegetables^[9], tree crops^[14], and field crops^[15].

Table 4: Water use efficiency for different irrigation treatments

Treatment	WUE (kg/m ³)	IWUE (kg/m ³)	Improvement (%)
Automated-DI	14.8 ± 1.2	15.2 ± 1.1	-
Manual-DI	11.4 ± 1.0	11.8 ± 0.9	29%
Furrow Irrigation	6.3 ± 0.8	6.7 ± 0.7	57%

The solar photovoltaic system successfully powered the automated irrigation system throughout the evaluation period, demonstrating the viability of solar energy for agricultural automation in off-grid locations. The 100W panel provided sufficient energy for continuous operation, with battery storage ensuring uninterrupted function during nighttime and cloudy periods. This finding supports the growing body of literature on solar-powered irrigation system^[10, 11].

The elimination of grid electricity dependence not only reduced operational costs but also improved system reliability in areas with unstable power supply. The environmental benefits of using renewable energy for irrigation align with global sustainability goals and carbon emission reduction targets^[12].

5. Economic Analysis

The economic analysis revealed a payback period of 3.6 years, which is favorable compared to many agricultural investments^[18]. The positive NPV and BCR greater than 1 indicate that the system is economically viable for farmers with adequate access to capital or financing options. The primary economic benefits stem from water savings, labor reduction, and potential yield improvements^[19]. Table 5 presents a detailed breakdown of the initial investment and annual operational costs for the automated drip irrigation

system.

Table 5: Cost breakdown for the automated drip irrigation system (per hectare)

Sl. No.	Component (Initial Investment)	Cost (INR)
1	Solar panel (100W)	8500
2	Battery (12V, 100Ah)	12000
3	Charge controller	2500
4	Microcontroller and sensors	6500
5	Pump and valves	15000
6	Drip irrigation components	32000
7	Installation and setup	5500
8	Total Initial Investment	82000
9	Annual Operational Costs	
10	Maintenance and repairs	3000
11	Battery replacement (amortized)	2400
12	Sensor replacement	800
13	Energy cost savings	-12000
14	Labor cost savings	-10000
15	Net Annual Operating Cost	-15800

Hence, Economic analysis revealed favorable indicators with a payback period of 3.6 years, positive NPV of INR 1,68,000, and BCR of 2.05, demonstrating economic viability for farmers.

6. Conclusions

This study successfully developed and evaluated a solar-powered automated drip irrigation system integrated with soil moisture sensors for precision water management. The system demonstrated significant water savings of 42% compared to conventional furrow irrigation and 18% compared to manual drip irrigation, while maintaining comparable or improved crop yields. Water use efficiency was markedly enhanced, reaching 14.8 kg/m³, which represents a 29% improvement over manual drip irrigation and 57% over furrow irrigation. The solar photovoltaic system ensured reliable and continuous autonomous operation, eliminating dependence on grid electricity and thereby reducing operational costs. Economic analysis indicated strong feasibility, with a payback period of 3.6 years, a positive Net Present Value (NPV) of INR 1,68,000, and a Benefit–Cost Ratio (BCR) of 2.05. Additionally, the system effectively maintained soil moisture within optimal levels throughout the growing season, preventing water stress and improving crop performance. The modular design, based on open-source microcontroller platforms and standard components, offers a cost-effective alternative to commercial systems while delivering comparable functionality.

Acknowledgments

The author acknowledges Aditya University, Surampalem for providing the experimental facilities for this research. We also appreciate the cooperation of local farmers who provided valuable insights during system development.

Conflict of Interest

The authors declare no conflict of interest.

References

1. FAO. The state of food and agriculture 2020: Overcoming water challenges in agriculture. Food and Agriculture Organization of the United Nations; 2020.
 2. Molden D, Oweis T, Steduto P, Bindraban P, Hanjra MA, Kijne J. Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management*. 2010;97(4):528-535.
 3. Burt CM, Clemmens AJ, Strelkoff TS, Solomon KH, Bliesner RD, Hardy LA, *et al.* Irrigation performance measures: Efficiency and uniformity. *Journal of Irrigation and Drainage Engineering*. 1997;123(6):423-442.
 4. Lamm FR, Ayars JE, Nakayama FS. Microirrigation for crop production: Design, operation, and management. *Developments in Agricultural Engineering*. 2007;13:1-618.
 5. Narayanamoorthy A. Impact assessment of drip irrigation in India: The case of sugarcane. *Development Policy Review*. 2004;22(4):443-462.
 6. Allen RG, Pereira LS, Raes D, Smith M. Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. Food and Agriculture Organization; 1998.
 7. Evans RG, Sadler EJ. Methods and technologies to improve efficiency of water use. *Water Resources Research*. 2008;44(7):W00E04.
 8. Vellidis G, Tucker M, Perry C, Kvien C, Bednarz C. A real-time wireless smart sensor array for scheduling irrigation. *Computers and Electronics in Agriculture*. 2008;61(1):44-50.
 9. Gutiérrez J, Villa-Medina JF, Nieto-Garibay A, Porta-Gándara MÁ. Automated irrigation system using a wireless sensor network and GPRS module. *IEEE Transactions on Instrumentation and Measurement*. 2014;63(1):166-176.
 10. Chandel SS, Naik MN, Chandel R. Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. *Renewable and Sustainable Energy Reviews*. 2015;49:1084-1099.
 11. Gopal C, Mohanraj M, Chandramohan P, Chandrasekar P. Renewable energy source water pumping systems—A literature review. *Renewable and Sustainable Energy Reviews*. 2013;25:351-370.
 12. Mekhilef S, Saidur R, Safari A. Comparative study of different fuel cell technologies. *Renewable and Sustainable Energy Reviews*. 2012;16(1):981-989.
 13. Dhawan V. Water and agriculture in India. Background paper for the South Asia Expert Panel during the Global Forum for Food and Agriculture. 2017:1-28.
 14. Fernández JE, Palomo MJ, Díaz-Espejo A, Girón IF. Influence of partial soil wetting on water relation parameters of the olive tree. *Agronomie*. 2003;23(4):545-552.
 15. Coates RW, Delwiche MJ, Brown PH. Control of precision irrigation with soil water potential. *Agricultural Water Management*. 2006;88(1-3):196-206.
 16. Sujatha G, Sai Krishna V. Assessment of mulch practices with drip irrigation on soil physical quality and weed regulation. *International Journal of Biological Sciences*. 2025;7(12):25-28.
 17. Sujatha G, Krishna Kanth B, Sinha J, Kalyani MS, Lakshmi TV, Srinu M. Comparative study of the impact of saline water irrigation on tomato yield, quality and growth in Andhra Pradesh, India. *International Journal of Plant and Soil Science*. 2023;35(20):1076-1085.
 18. Krishna VS, Jain SK, Panwar NL, Wadhawan N. Emergence of IoT in the field of food and agricultural sector. *Journal of Food Process Engineering*. 2024;47(8):e14698.
- Krishna VS, Jain SK, Panwar NL, Rama Sree. An overview on phase change material incorporated in convective solar dryers. *Journal of Energy Storage*. 2025;131.