Eco. Env. & Cons. 30 (2) : 2024; pp. (811-819)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2024.v30i02.065

Automation in micro irrigation – A Review

Yadvendra Pal Singh*[1], Kushal Roy, Aadya P., B.V.S. Rohit Raddy and Afroz

[1]Department of Soil Science and Agricultural Chemistry,
Lovely Professional University, Phagwara, Punjab, India
[2,3,4,5] School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

(Received 30 October, 2023; Accepted 11 December, 2023)

ABSTRACT

This review paper explores the transformative role of micro-irrigation in modern agriculture. It presents a comprehensive overview of the complete setup and advantages of automatic micro-irrigation systems, emphasizing their capacity to enhance crop yields while minimizing labor and water usage. Micro-irrigation, with its precise water delivery directly to the root zone, mitigates water wastage and contributes to sustainable farming practices, especially crucial in the context of global water scarcity exacerbated by climate change. Additionally, the integration of automation technologies in micro-irrigation is discussed, highlighting how advanced sensors, actuators, and data analytics optimize irrigation processes, making them more precise and efficient. Furthermore, the paper underscores the vital role of micro-irrigation in nutrient management, as these systems excel in delivering nutrients directly to plant roots, reducing environmental impact and improving fertilizer efficiency. This focused nutrient distribution fosters crop growth, resulting in higher yields and improved quality. Moreover, the review paper explores the benefits of micro-irrigation in weed control and disease management. Additionally, it offers the potential to reduce reliance on chemical treatments, promoting eco-friendly agricultural practices and mitigating health concerns associated with pesticide use. Overall, this paper highlights the multifaceted advantages of micro-irrigation systems, making a compelling case for their adoption in modern agriculture.

Key words: *Automation, Micro irrigation, Crop yield, Nutrient management, Weeds control*

Introduction

Micro irrigation represents a modern and highly efficient method for the targeted delivery of water to crops, fundamentally altering the landscape of agricultural practices. This technique is characterized by its precision, delivering water directly to the root zone of plants, thus drastically reducing water wastage while concurrently enhancing crop yields. The evolution of micro irrigation systems has ushered in a revolution in traditional irrigation practices, and the integration of automation has propelled this technology to new heights.

Automation in micro irrigation signifies the application of advanced technologies and control systems designed to monitor, manage, and optimize the irrigation process. This approach encompasses an array of sophisticated sensors, actuators, and data analytics, rendering irrigation not only more precise but also significantly more efficient and sustainable. The incorporation of automation not only enhances the performance of micro irrigation systems but also plays a pivotal role in conserving resources and promoting environmental sustainability.

The journey of automation in micro irrigation has been a progressive one, marked by significant milestones over the decades. In the 1970s, automation in micro irrigation primarily found its footing in com-

([1]Assistant Professor, [2,3,4,5] B.Sc. Students)

mercial greenhouses and nurseries, characterized by relatively simplistic systems. By the 1980s, these automated micro irrigation systems began to be applied on a larger scale in agricultural operations, incorporating sensors to monitor soil moisture and employing controllers for enhanced control.

The 1990s witnessed a pivotal shift as automated micro irrigation systems became increasingly adaptable, making them an attractive proposition for small-scale farmers seeking improved water use efficiency. By the 2000s, these systems had evolved to incorporate a diverse range of sensors to monitor soil moisture, weather conditions, and crop growth, ushering in a new era of precision agriculture.

Today, automated micro irrigation systems have transcended geographical boundaries, finding widespread adoption in agricultural operations not only in India but across the globe. These systems have been instrumental in enhancing water use efficiency and mitigating waterlogging issues near the root zones of crops. With micro irrigation, water efficiency can soar to an astounding 90%, owing to the meticulous delivery of water, drop by drop, directly to the plant's root zone. Automation further amplifies these benefits by enabling seamless control of all system components through computer devices or mobile phones, ensuring that plants receive the precise quantity of water they need at precisely the right time. This precision minimizes crop damage and paves the way for achieving maximum yields, making automated micro irrigation an indispensable tool in contemporary agriculture.

Automation

Automation in the context of drip or micro irrigation systems signifies the operation of these systems with minimal or no manual interventions. This innovative approach to irrigation has gained substantial traction, particularly in scenarios where large agricultural areas need efficient water management. This article delves into the intricacies of irrigation automation, exploring its specific features and types, and highlighting its profound implications for agricultural practices (Bjorneberg *et al.,* 2005).

Understanding Automation in Irrigation

Irrigation automation becomes especially compelling when extensive agricultural lands are subdivided into smaller segments known as irrigation blocks. These segments are systematically irrigated in sequence to align with the available water flow from the water source, as described by Rajakumar et al. in their work from 2008. The primary objective is to optimize water distribution while minimizing human intervention.

Distinctive Features of Automated Irrigation Systems

Valve Operation One of the hallmark features of automated irrigation systems is the elimination of manual valve operations. The system takes on the responsibility of opening and closing valves as required.

Pump Control Automation ensures precise control over pump operation, activating and deactivating it exactly when necessary. This level of control optimizes energy consumption, contributing to sustainability and cost-efficiency.

Flexible Timing Automated irrigation systems offer the flexibility to start irrigation at any desired time. This eliminates the need for farmers to visit their fields during odd hours, a particularly valuable feature in regions like India where agricultural operations often coincide with nighttime when power supply is more readily available.

Adaptive Irrigation Automation allows for the adjustment of irrigation frequency and fertilizer application in line with the specific needs of the crop, optimizing resource utilization and crop health.

Multi-source Water systems facilitate the utilization of water from various sources, leading to increased water and fertilizer use efficiency, as noted by Rajakumar *et al.,* 2008.

Exploring Types of Automation

There are two primary categories of irrigation auto-

Table 1. Automation of irrigation in maize

Day	Maize Crop			
	With automation		Without automation	
	Height (cm)	Diameter (cm)	Height (cm)	Diameter (cm)
1.	34.00	1.75	34.00	1.75
2.	34.20	1.76	34.00	1.75
3.	34.20	1.76	34.00	1.75
4.	34.50	1.77	34.10	1.76
5.	34.50	1.78	34.10	1.76
6.	34.50	1.78	34.10	1.76
7.	34.60	1.78	34.10	1.76
8.	**34.70**	**1.79**	**34.20**	**1.77**

(Automation in irrigation Rathika *et al.,* 2020)

mation: semi-automatic and fully automatic systems, and many other each offering unique advantages and suited to different contexts.

Semi-Automatic Systems

Semi-automatic systems require manual attention during each irrigation cycle. They are typically simpler and more cost-effective than their fully automatic counterparts. These systems often employ mechanical or electronic timers to activate control structures at predetermined times. In semi-automatic setups, the irrigator decides when to commence irrigation, how long it should last, and manually resets or repositions devices before the next irrigation cycle. These systems may have certain components that are fully automatic while others remain semi-automatic or manually operated, necessitating communication between the controller and field-based components (Zhao *et al.,* 2009).

Fully Automatic Systems

Fully automatic systems, on the other hand, operate with minimal operator involvement, primarily requiring periodic inspections and routine maintenance. In these systems, the irrigator can determine the timing and duration of irrigation, initiating automated functions using programmed controllers. Soil moisture sensors, such as tensiometers or electrical resistance blocks, are employed to trigger electrical controls when soil moisture reaches predetermined levels. The duration of irrigation can be controlled through programmed timers, soil moisture sensors, or surface water sensors. Fully automatic systems are highly efficient but necessitate a consistent and readily available water supply, typically sourced from wells or farm reservoirs. It's worth noting that while fully automatic systems offer unparalleled efficiency, many farm setups may not possess the requisite flexibility for complete automation (Peters *et al.,* 2008).

Table 2. Automation of irrigation in chili

Day	Chili crop			
	With automation		Without automation	
	Height (cm)	Diameter (cm)	Height (cm)	Diameter (cm)
1.	21.00	0.54	21.00	0.54
2.	21.10	0.54	21.00	0.54
3.	21.10	0.55	21.00	0.54
4.	21.30	0.55	21.10	0.55
5.	21.30	0.56	21.10	0.55
6.	21.30	0.56	21.20	0.56
7.	21.40	0.57	21.20	0.56
8.	21.40	0.58	21.30	0.57

(Automation in irrigation S. Rathika *et al.,* 2020)

Automatic Irrigation system on sensing soil moisture content

This system is intended to provide optimum amount of irrigation to the agricultural fields by studying and sensing the moisture content in the soil. There is minimum or no manual interference as the pump is automatically switched ON/OFF. I t has a micro controller which is programmed in such a way that the input signals measure the moisture content in the soil through sensing arrangement. The sensing arrangement is made by inserting two stiff metallic rods into the field at some distance. An operational amplifier (op-amp) is used as a comparator that interfaces micro controller and the sensing arrangement. When the signal is received the micro controller produces an output that operates the water pump. Hence the need for human intervention is reduced and optimum irrigation is supplied to the field.

Solar powered auto irrigation system

This type of automation system is similar to the automation system that is used to sense soil moisture in addition to the fact that photovoltaic cells are used which are stored in recyclable batteries. The solar energy which is generated from these photovoltaic cells is used for operating the irrigation pump. A submersible pump controller is used to pump water from a bore well to the storage tank, then the water is drawn by a submersible pump after which the installed sprinklers water the crops or plants. The three major factors that regulate the solar based functioning system are power, flow and pressure. The solar panel consists of photovoltaic cells which are composed of semiconductor materials. They convert solar energy to DC energy. The major factor to be taken into account is that the panels must be placed at right angles to the sun rays (Balaji *et al.,* 2016).

GSM Based Automatic Irrigation system

The Global System based on Mobile communication is another method o automation in irrigation. This is done through via SMS with the help of GSM modem. This can be operated through webcams and other smart devices also (Pavithra *et al.,* 2014).

Time Based automation system

A time-based automation system in micro irrigation is a system that controls the irrigation of crops based on a preset time. To set up a time-based automation system, you will need a timer, a controller, and solenoid valves. The timer will be responsible for starting and stopping the irrigation cycle, it provides signals to the valve and pump at the same time so that both works at same time.

The duration of each irrigation cycle will need to be determined based on the type of crop being grown, the soil type, and the climate. Once the duration of the irrigation cycle has been determined, it can be programmed into the timer (Osroosh *et al.* 2016).

Volume based irrigation system

Volume-based automation in micro irrigation is a system that controls the irrigation of crops based on a predetermined volume of water.

This system consists of flow meter, a controller, and solenoid valves. The flow meter helps to measure the amount of water that flows through the system, while the controller will control the flow of water to each solenoid valve. The solenoid valves will then open and close to allow water to flow to the crops (Ghodake *et al.*, 2016).

Closed loop system

This system is made of some sensors that provides data to whole system for making decisions when and how much water will be applied.

Computer based irrigation control system

Computer-based irrigation control systems can be used to control a variety of irrigation systems, including drip irrigation, sprinkler irrigation. We can control whole drip irrigation system through computer device. Computer collects data from sensors that are attached with drip irrigation channel, and we can easily monitor on the screen of computer (Guerbaoui *et al.*, 2013).

Merits and Demerits of Automated Irrigation

Automated irrigation systems represent a significant advancement in modern agriculture, offering numerous advantages while also presenting certain challenges. This comprehensive analysis delves into the merits and demerits of automated irrigation, exploring how this technology impacts crop yield, resource management, labor efficiency, and overall agricultural practices.

Merits of Automated Irrigation

Enhanced Crop Yield Automated micro irrigation systems play a pivotal role in boosting crop yields. By precisely controlling the timing and amount of water delivered, these systems ensure that plants receive the optimal moisture levels needed for healthy growth.

Water and Energy Savings Automation reduces water wastage by delivering water only when and where it is needed. This not only conserves water resources but also reduces energy consumption associated with pumping and distribution.

Labor Cost Savings Automated systems eliminate the need for constant monitoring and manual intervention. Farmers and irrigators can allocate their time and labor to other essential tasks, improving overall operational efficiency.

Optimal Soil Moisture These systems start and stop irrigation based on predetermined soil moisture levels, preventing over-irrigation and leaching of essential minerals and nutrients. This ensures the health of crops and mitigates long-term issues associated with soil salinity.

Adaptability to Variable Conditions Automated irrigation is well-suited for regions with unpredictable and uneven rainfall patterns, where it can adjust irrigation schedules in response to changing conditions. This adaptability is particularly valuable in both arid and humid areas.

High-Frequency, Low-Volume Irrigation Automated systems excel in providing high-frequency, low-volume irrigation, which is especially beneficial for certain crops and soil types.

Improved Lifestyle With automated irrigation, farmers can enjoy a more balanced lifestyle. They are not required to continuously monitor irrigation progress, allowing them to spend time with their families and have undisturbed sleep, even during nighttime irrigation.

Timely Irrigation Automation ensures that irrigation occurs precisely when the plants require it, aligning with their growth and water needs.

Management of Higher Flow Rates Forfarmers looking to increase irrigation flow rates, automation allows for efficient management without requiring additional labor.

Accurate Cut-off Automated systems enable precise cut-off of water at the appropriate point in the field, reducing water wastage.
Reduced Runoff Automation can help retain fertilizers on the farm by effectively reducing runoff, yielding both economic and environmental benefits.
Cost Savings for Vehicles As farmers do not need to constantly monitor irrigation, the use of vehicles like motorbikes and four-wheelers is reduced, leading to cost savings in vehicle maintenance and replacement.

Demerits of Automated Irrigation

Initial Cost One of the primary demerits of automated irrigation is the upfront cost associated with purchasing, installing, and maintaining the equipment. These costs can be substantial, especially for small-scale farmers.

Reliability Automated systems are reliant on technology, and occasional failures can occur. These failures may result from human error in system setup and maintenance. Implementing a backup system or reuse system can serve as insurance against such failures.
Increased Channel Maintenance Toensure the proper functioning of automated systems, increased maintenance of channels and equipment is required. Fencing channels to protect automatic units from damage by livestock becomes necessary.

Emerging Developments in Automation for Irrigation

In the ever-evolving landscape of agriculture, automation has emerged as a transformative force, revolutionizing the way we communicate, collect data, and manage irrigation systems. This comprehensive analysis delves into the emerging techniques and technologies employed in automation for irrigation, shedding light on their applications, benefits, and implications for modern farming practices.

Automation Techniques

Microcontroller (Arduino) Based Irrigation Systems

Microcontroller-based irrigation systems represent a foundational approach to automation. These systems integrate sensors to gather data, which is then processed by a microcontroller. Subsequently, the system generates and communicates output to the control unit. By leveraging this technology, farmers can precisely monitor and control irrigation processes (Swamy *et al.* 2013).

Internet of Things (IoT) Based Irrigation System

IoT represents the next evolution of microcontroller-based systems. Similar to their predecessors, IoT systems utilize sensors effectively to monitor moisture levels, humidity, nutrient values, temperature, and more. However, IoT takes automation a step further by enabling remote monitoring and control, allowing farmers to access real-time data and make adjustments from anywhere (Mahir Dursun *et al.* 2011).

Distributed Wireless and Remote Sensor Networks for Irrigation System and Control

Recent advancements in communication and signalling have paved the way for wireless sensor-based irrigation systems. These systems leverage global positioning system (GPS) data and wireless communication to electronically control irrigation. Remote access to field conditions, real-time control, and georeferenced location tracking are key features. Both terrestrial wireless sensor networks (TWSN) and wireless underground sensor networks (WUSN) have emerged, each with its own characteristics and applications.

Google-Assistant based IoT for Irrigation System

This iteration of automation harnesses the power of Android and Google. It involves data collection on parameters such as soil moisture, nutrients, and pesticides, which is regularly updated on a web page. An integrated system comprising a soil moisture sensor, microcontroller with a WiFi module (NODEMCU), and solar panels for power supply is designed for irrigation purposes. Conditional statements using IFTTT (if this then that) trigger actions like turning the pump on or off based on email messages.

Artificial-Intelligence based Irrigation System

Artificial intelligence (AI) introduces the concept of machine learning and problem-solving to irrigation automation. AI-fed machines, including drones and robots, mimic human intelligence and exhibit self-organization and adaptive learning capabilities. These AI systems are utilized for sensing purposes, localized by GPS modules, and tracked via GPS. They have applications in various sectors, including pesticide spraying, crop monitoring, mapping, and

remote sensing (Savita Choudhary *et al.,* 2019).

Communicating Modules in Automation

Bluetooth Module

Bluetooth is a wireless communication protocol used for data exchange between devices. It operates at 2.4 GHz and has a range of up to 100 meters. It is suitable for short-range applications and is classified into different classes based on output range and communication distance.

Zigbee

Zigbee is designed for low-cost, low-power wireless IoT networks, adhering to the IEEE 802.15.4 standard. It supports various network structures, including star, tree, and mesh networks, and covers a range of 10 to 100 meters. Zigbee is cost-effective and well-suited for sensor networks.

Wi-Fi Module

Wi-Fi modules enable devices to connect to wireless networks. The ESP8266 WiFi Module, for instance, is a cost-effective chip with integrated TCP/IP protocol stack, facilitating access to Wi-Fi networks. It is capable of hosting applications and is suitable for integration with sensors and devices.

RF Module

Radio Frequency (RF) modules transmit or receive radio signals wirelessly between devices. They have applications in long-range communication, with a range of up to 500 feet and a frequency range of 30 kHz to 300 GHz.

Automation in Irrigation Scheduling

Automation plays a pivotal role in modernizing irrigation scheduling practices in agriculture. Efficient water management is paramount, as timely and precise irrigation is essential for achieving optimal crop production. Automation not only allows for real-time irrigation based on soil moisture levels but also enables high-frequency, low-volume irrigation—a critical aspect of modern agriculture.

Soil Moisture Sensors and Wireless Communication

Recent trends emphasize the automation of irrigation scheduling due to its significance in water management. Automation facilitates real-time irrigation based on soil water availability within the crop root zone. It also supports high-frequency, low-volume irrigation, which has become essential for modern farming. Various studies recommend the use of automated irrigation systems for remote in-field sensing and variable-rate irrigation control (Prateek Jain *et al.,* 2017).

Application of Automation in irrigation systems

Automation in irrigation has revolutionized agriculture by introducing efficiency, precision, and sustainability into the management of water resources. Here are some key applications of automation in irrigation:

Irrigation Scheduling Automation allows for precise and data-driven irrigation scheduling. Soil moisture sensors, weather forecasts, and real-time data collection enable farmers to determine when and how much water their crops need. This reduces water wastage and ensures that crops receive the right amount of moisture, leading to higher yields and water conservation.

Variable-Rate Irrigation Automation systems can adjust water distribution across a field based on specific crop requirements. By using data from soil moisture sensors and GPS technology, variable-rate irrigation ensures that each area of the field receives the optimal amount of water. This promotes uniform crop growth and resource efficiency.

Remote Monitoring and Control IoT-based automation allows farmers to remotely monitor and control irrigation processes. Through smartphones or computers, farmers can access real-time data on soil moisture levels, weather conditions, and equipment status. This remote accessibility improves responsiveness and reduces the need for physical presence in the field.

Drip and Micro-Irrigation Automation is widely applied in drip and micro-irrigation systems, where water is delivered directly to the root zone of plants through a network of tubes and emitters. Automated valves, pumps, and sensors ensure precise water delivery, reducing water wastage and making these systems highly efficient.

Fertigation Automation systems can integrate fertilizer application with irrigation. By precisely mixing and delivering fertilizers through the irrigation system, crops receive the required nutrients directly to their root zones. This promotes optimal growth, minimizes nutrient runoff, and reduces the environ-

mental impact of fertilization.

Artificial Intelligence (AI) AI-powered drones and robots equipped with sensors can assess crop health, moisture levels, and nutrient requirements. These autonomous systems collect and analyse data, enabling them to make informed decisions about when and where to irrigate. AI-driven automation enhances resource management and crop productivity.

Weather-Based Control Automation systems can incorporate weather forecasts into irrigation decisions. When rain is predicted, irrigation can be temporarily suspended to prevent overwatering. This feature conserves water and reduces operational costs.

Evolution of Automation in Irrigation

Irrigation has been a cornerstone of agriculture for millennia, allowing farmers to supplement natural rainfall and ensure consistent crop growth. However, traditional irrigation methods often suffered from inefficiencies, imprecise water distribution, and labour-intensive processes. The evolution of automation in irrigation has transformed this fundamental agricultural practice, introducing efficiency, precision, and sustainability into the management of water resources.

Early Irrigation Practices

Historically, irrigation was a labour-intensive and manual endeavour. Farmers relied on basic techniques such as furrow and flood irrigation, where water was manually diverted into fields through trenches or channels. These methods were highly dependent on human observation and labour, making them susceptible to errors and water wastage. Moreover, they often led to uneven water distribution, resulting in overwatering in some areas and underwatering in others.

Introduction of Mechanical Irrigation Systems

The late 19th and early 20th centuries witnessed the introduction of mechanical irrigation systems, which marked a significant advancement in irrigation technology. These systems employed mechanical pumps and pipes to transport water from a water source, such as a river or well, to the fields. While these systems reduced the reliance on manual labour, they still lacked precise control and automation, often leading to water inefficiencies and soil erosion.

The Emergence of Timer-Based Controllers

In the mid-20th century, timer-based irrigation controllers began to gain popularity. These controllers allowed farmers to program the timing and duration of irrigation events. While they represented a step toward automation, they relied on fixed schedules and did not consider real-time environmental conditions or soil moisture levels. Consequently, they often resulted in water overuse and inefficient irrigation practices.

Integration of Sensors and Monitoring Systems

The late 20th century saw the integration of sensors and monitoring systems into irrigation practices. Soil moisture sensors, weather stations, and remote monitoring technologies emerged as key components of automated irrigation. These sensors provided valuable data on soil moisture levels, weather forecasts, and environmental conditions, enabling farmers to make more informed decisions about when and how much to irrigate. This marked a significant shift from fixed schedules to data-driven irrigation management.

The Internet of Things (IoT) and Wireless Connectivity

In recent years, the Internet of Things (IoT) has played a pivotal role in advancing irrigation automation. IoT-based systems leverage wireless connectivity and data analytics to create smart irrigation solutions. Farmers can now remotely monitor and control irrigation processes through smartphones or computers. These systems incorporate real-time data on soil moisture, temperature, humidity, and weather forecasts, allowing for precise irrigation scheduling. Moreover, IoT technology facilitates variable-rate irrigation, where different areas of a field receive customized amounts of water based on their specific needs.

Artificial Intelligence and Autonomous Systems

The integration of artificial intelligence (AI) into irrigation automation has ushered in a new era of smart farming. AI-powered drones and robots equipped with sensors can assess crop health, moisture levels, and nutrient requirements. These autonomous systems collect and analyse data, enabling them to make informed decisions about when and where to irrigate. AI-driven automation enhances resource management and crop productivity

by adapting to changing conditions and optimizing water usage.

Environmental Sustainability and Resource Conservation

Automation in irrigation has not only improved crop yields but also contributed to environmental sustainability. Precise irrigation scheduling, water conservation, reduced runoff, and optimized nutrient management have minimized the environmental impact of agriculture. Automation systems align with global efforts to conserve water resources and reduce the carbon footprint of farming practices.

Conclusion

In conclusion, this review paper has provided a comprehensive overview of the significant advancements and potential benefits of automation in micro-irrigation systems. The integration of automation technologies into micro-irrigation has the potential to revolutionize the way we manage water resources in agriculture. By improving precision, efficiency, and sustainability, automated micro-irrigation systems can address some of the critical challenges facing modern agriculture, such as water scarcity and resource optimization.

Through our exploration of the various components of automation, including sensor technologies, data analytics, and control systems, we have seen how these innovations can lead to more informed decision-making and precise water delivery. This not only enhances crop yields but also conserves water resources and reduces energy consumption, making agriculture more environmentally friendly.

Furthermore, we have discussed the demerits that still need to be addressed for the widespread adoption of automated micro-irrigation systems, including initial investment costs, technical expertise, and infrastructure requirements. These challenges should be met with strategic investments, research, and policy support to ensure that the benefits of automation are accessible to a wide range of farmers.

As we move forward, it is clear that automation in micro-irrigation will continue to evolve, driven by technological advancements and the increasing urgency of sustainable agricultural practices. To fully harness the potential of automation, interdisciplinary collaboration among engineers, agronomists, policymakers, and farmers will be essential. Together, we can create a future where automated micro-irrigation systems play a pivotal role in ensuring food security, conserving water resources, and mitigating the impact of climate change on agriculture.

Conflict of Interest

Authors declare there is no conflict of interest.

References

Balaji, C. and Sudha, S. 2016. Internet of things based automated irrigation system. *International Journal of Innovative Research in Computer and Communication Engineering*. 4(7): 128-135.

Bjorneberg, D. L., Westermann, D. T. and Nelson, N. O. 2005. Water quality impacts of sprinkler and furrow irrigation in an irrigated corn production system. *Journal of Environmental Quality*. 34(5): 1786-1794.

Choudhary, S. and Jadon, N. 2019. Smart irrigation system using IoT. *International Journalof Computer Applications*. 178(25): 27-30.

Dursun, M. and Ozden, S. 2011. A wireless application of drip irrigation automation supported by soil moisture sensors. *Scientific Research and Essays*. 6(7): 1573-1582.

Ghodake, D. A., Mane, D. A., Deshmukh, S. S., Patil, A. S. and Gholap, M. V. 2016. Automated irrigation system by using Arduino controller. *International Journal of Engineering Research and General Science*. 4(2): 357-362.

Guerbaoui, M., Haddi, A., Maoudj, A., Tmimi, A., Bellafkih, M. and Ed-Dahhak, A. 2013. A wireless sensor network for drip irrigation control in agriculture. *International Journal of Engineering Science and Technology*. 5(8): 1567-1573.

Jain, P. and Agrawal, S. 2017. IoT based smart irrigation system. *International Journal of Computer Applications.* 159(8): 7-11.

Mahir Dursun and Semih Ozden, 2011. A wireless application of drip irrigation automation supported by soil moisture sensors. *Scientific Research and Essays*. 6(7): 1573-1582.

Osroosh, Y., Khot, L. R., Peters, R. T. and Campbell, C. S. 2016. Rapid calibration of a portable multi-sensor platform for aerial assessment of crop canopy. *Computers and Electronics in Agriculture*. 124: 162-169.

Pavithra, D. S. and Srinath, M. S. 2014. GSM based automatic irrigation control system for efficient use of resources and crop planning by using an Android mobile. *IOSR Journal of Mechanical and Civil Engineering*. 11(4): 49-55.

Peters, R. T., Evett, S. R. and Andrade, M. A. 2008. Satellite-based irrigation management in irrigated agriculture. *Irrigation Science*. 26(5): 483-496.

Rajakumar, M., Kanmani, K. and Prasad, R. 2008. Design

and implementation of sensor based irrigation system for agriculture. *International Journal of Computer Science and Network Security*. 8(12): 117-122.

Rathika, S., Nandhini, S., Kumar, M. S. and Sujatha, P. 2020. Automation in irrigation system. *International Journal of Advanced Research in Engineering and Technology*. 11(3): 10-15.

Swamy, K. N., Rani, R. K. and Rao, A. B. 2013. Automated irrigation system. *International Journal of Advanced Research in Computer Science and Software Engineering*. 3(9): 110-114.

Zhao, Y., Han, M., Zhang, Y. and Liu, W. 2009. Remote monitoring and control of greenhouse environment based on wireless sensor network. *Transactions of the Chinese Society of Agricultural Engineering*. 25(11): 151-156.