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INNOVATIVE TECHNOLOGIES IN SPRINKLER IRRIGATION: AN OVERVIEW

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ABSTRACT

The overuse of water in conventional irrigation at the farm level is a global issue that can be addressed by improving irrigation techniques. Sprinkler irrigation can reduce water losses by carefully planning the crop, soil, landscape, and weather conditions, as well as installing the proper sprinkler hardware. The application efficiency of sprinkler systems may be enhanced when these systems are coupled with automation for precise irrigation. Sprinkler irrigation has advanced significantly, but new ideas and current practices are driving further progress. These novel ideas include low-pressure sprinklers, smart controllers, fertigation, water-pesticide integrated sprinkler systems, and variable-rate irrigation. The objective of this work is to highlight the introduction of innovative technologies to optimize sprinkler irrigation systems. Suggestions for the future development of sprinkler irrigation technology are offered to ensure its long-term viability.

Keywords: fertigation, water-pesticide integration, variable rate irrigation, water use efficiency, irrigation efficiency, internet of things (IoT).

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INTRODUCTION

Irrigation is the artificial application of water to soil or plants at the appropriate time and quantity, lowering the risk of production loss due to drought by supplying soil moisture to meet crop water requirements. Watering cans, sprinklers, drip irrigation, surface irrigation systems, and other methods can be used to practice irrigation, which is typically done using surface and pressurized systems and is distinguished by how water is transported to the application site (Keller and Bliesner, 1990).

The world's irrigated area accounts for 272 million ha at present, which represents 18 % of the cultivated area. Irrigated agricultural land accounts for approximately 90 % of total crop production (Khan *et al*., 2016). According to world statistics, India has the most irrigated agricultural land (55 ha), followed by China, the USA, Pakistan, Iran, Mexico, Thailand, Indonesia, Russia, and Turkey (Figure 1) (Schultz *et al*., 2005).

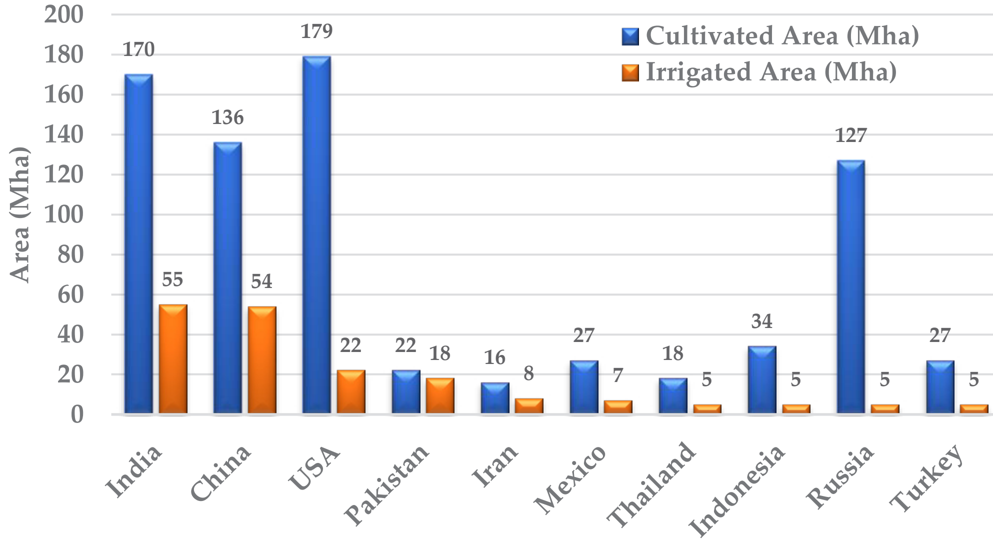

Figure 1. Cultivated and irrigated areas of the top ten countries (Schultz *et al.*, 2005).

Agriculture is the most water-intensive sector, accounting for 70 % of total freshwater withdrawals. However, in some developing countries, this percentage can reach as high as 95 % (FAO, 2015, 2017). The agricultural sector is often criticized for having low efficiency and high-water use. It is highly unlikely that more significant water resources will be made available to agriculture in the future because of the competing water needs of other sectors. Also, because of an increase in population and prosperity, there is an ongoing grow in demand for food, fiber, and housing to satisfy basic needs. Therefore, irrigated agriculture must be more efficient, cost-effective, and flexible. This is possible by updating and modernizing the irrigation systems.

The lack of effective irrigation techniques causes the overuse of water, which lowers crop productivity in most parts of the world. Research shows that most irrigation methods are inefficient because less than half of the water reaches the crop (Li *et al.*, 2019; IFPRI, 2014). Therefore, irrigation system reforms are required to enhance crop yield and satisfy future food needs. Irrigation can boost crop yield per hectare by 2.3 times compared to rainfed areas (Kannan, 1986; Siebert and Doll, 2010).

Sprinkler irrigation systems are becoming increasingly popular, particularly in regions where the terrain is not conducive to traditional irrigation methods. Its adoption in America, Europe, Asia, Africa, and Oceania is 13.3, 10.1, 6.8, 1.9, and 0.9 Mm^2, respectively (Xia *et al.*, 2017). Sprinklers discharge water as tiny droplets when highly pressurized water is forced through them. A sprinkler system is especially suitable for sandy soil, but it is adaptable to almost all soil types. The average application rate of water must be less than the basic infiltration rate of the soil just to prevent water from ponding on the soil surface.

Mechanical and hydraulic devices are used in sprinklers to apply water to the soil surface. With sprinkler irrigation systems, it is possible to apply water, fertilizer, and pesticides efficiently in the right amount at the appropriate times, reducing the occurrence of plant diseases, inhibiting weed growth, and creating favorable conditions for crop growth. This enhances crop productivity and product quality (Kulkarni, 2011). Using sprinkler irrigation, field crop yields may be raised by 10–20 %, while vegetable crop yields could be enhanced by 30 % (Zou *et al.*, 2012). However, sprinkler fertigation keeps crop foliage wet, increasing the risk of pests, diseases, and foliage burn. Additionally, the nutrients may spread to other locations where roots are dormant, reducing the effectiveness of fertilizers.

Sprinkler irrigation with proper design offers higher application efficiency and helps to prevent runoff. It can also help reduce water loss by planning the crops, soil, landscape, and weather conditions when installing the proper sprinkler hardware. Different types of nozzles can be used in pivoting and lateral move sprinkler irrigation systems. The sprinkler head can be altered by nozzles into different devices that utilize 20 % less water (Urrego-Pereira *et al.*, 2013; Wang *et al.*, 2015). Under certain operational conditions, the water is sprayed by these nozzles in multiple streams that combat the winds more effectively and uniformly than conventional sprays (Rahman and Singh, 2014).

Many new technologies have been introduced in sprinkler systems to increase their adaptability and to save water and chemicals like fertilizer and pesticides. This review depicts the induction of innovative technologies and ideas in sprinkler irrigation systems to optimize system productivity.

HISTORY OF DEVELOPMENT IN SPRINKLER IRRIGATION

Sprinkler irrigation technology was introduced almost a century ago, but its application in large areas has only occurred in the past eight decades. As of the end of 1970, more than 3 million hectares of land in the USA and 2.5 million ha in Europe had sprinkler irrigation. In many regions of the world, salinity problems were caused by poorly managed surface irrigation. Fixed sprinkler systems were the first application of sprinkler irrigation. In the 1930s, rotating sprinklers were gradually introduced in the USA, UK, France, Germany, and Italy. After the Second World War, tremendous improvements occurred due to the development of plastics, light aluminum pipes, internal combustion engines, efficient pumps, and electric motors. At that time, towed, center-pivot, mobile, self-propelled, reel traction, and other sprinklers were developed, improving sprinkler irrigation technology worldwide (Shankar *et al.*, 2018).

There are two types of sprinkler irrigation: low-pressure and high-pressure sprinklers (Ella *et al.*, 2008; Li, 2020). Every country develops sprinkler systems and equipment based on prevalent local conditions. In the USA, for instance, self-propelled and center-pivot sprinklers are encouraged. Australia, France, and Germany employ hose reel irrigation systems, whereas Russia uses double cantilever sprinklers. Since the

1950s, China has been at the forefront of development, promoting and implementing sprinkler irrigation as one of the most effective methods for conserving water during irrigation. The first significant change occurred when sprinkler-irrigated acreage increased from 0.03 % in 1974 to 1.42 % in 1985.

The Chinese government adopted water-saving irrigation as a key national policy in the middle of the 1990s because of growing public awareness of worldwide water concerns and the rising need for water resources for economic development. Since then, large amounts of funding have been dedicated to the research and promotion of water-saving irrigation technologies, and sprinkler irrigation development has advanced to a new stage (Yan *et al.*, 2020). In 2008, the Chinese government determined a new strategy for land transfer reforms in rural areas, creating agricultural business units that include family farms, major growers, and agricultural cooperatives. The sprinkler-irrigated area in China reached 4.6 million hectares by the end of 2020 (Figure 2), but this only accounts for 6.3 % of the irrigated area in China (Feng *et al.*, 2023).

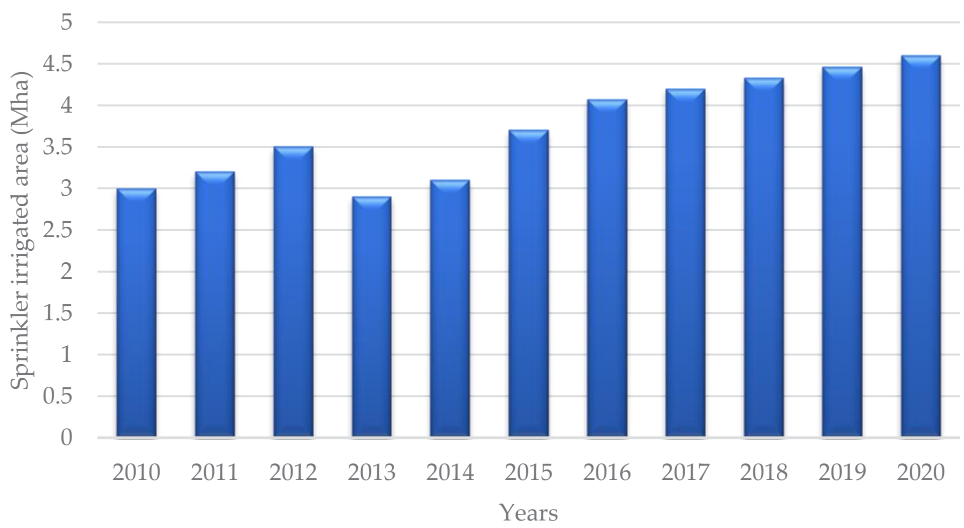

Figure 2. Sprinkler-irrigated area in China (Yan *et al.*, 2020; Feng *et al.*, 2023).

China still has substantial development potential for sprinkler irrigation technologies. To improve efficiency and minimize the management and labor costs of sprinkler irrigation systems, many countries are increasing the area under single-machine control. Worldwide research is also being explored on sprinkler irrigation-based fertigation. Because of rising energy costs worldwide, there has been a paradigm shift away from using high-pressure sprinklers and toward low-pressure sprinklers. As a result, researchers are working to enhance the performance of high-pressure sprinklers in low-pressure conditions, and irrigators around the world are becoming more interested in the development of water-pesticide-fertilizer integrated sprinkler irrigation and intelligent controllers.

NEW AND ADVANCED TECHNOLOGIES IN SPRINKLER IRRIGATION

Low-pressure sprinklers for the sustainability of farming

New technologies have emerged in sprinkler irrigation to increase system efficiency, water use efficiency, and reduce labor and operating costs. Unpredictable precipitation and rising temperatures already make agriculture challenging. The increasing electricity costs and decreasing the economic feasibility of farming complicate things more. Improving irrigation practices is one of the most straightforward actions to maintain sustainable earnings. Water pumping is often considered the largest energy consumer at the farm level. While farmers cannot simply terminate their field irrigation systems, they may adopt innovative energy-saving technologies.

The first step is to convert high-pressure irrigation to low-pressure, energy-efficient systems. Impact sprinklers release high volumes of water at pressures of 200 to 415 kPa. Most effective systems employ low-pressure sprinkler heads operating at 65 to 175 kPa. These sprinklers lower the need for pumping without considerably lowering the flow, enabling farmers to ensure that their crops have an adequate water supply while reducing the size of their pumps or allowing the modification of their impellers to lower the horsepower requirements (Alvarez, 2015).

By improving irrigation efficiency, low-pressure sprinklers save energy. A concentrated stream of tiny water droplets is released into the atmosphere using high-pressure impact sprinklers. High-pressure sprinklers produce small droplets that are easily dispersed by the wind and rapidly evaporate in dry weather. Meanwhile, low-pressure sprinklers produce larger droplets that are more resistant to high winds and evaporation. Impact sprinklers distribute water in a concentrated stream that severely disturbs the soil, compacting the surface and creating runoff. They generally cover their circle area in 60 to 120 s.

Sprinklers cannot be utilized at lower operating pressures if designed for higher operating pressures. Every type of sprinkler can perform its intended function within a range of flow rates and pressures. This helps them to maintain a proper droplet size and uniform application patterns. Impact sprinkler application patterns are distorted, and their efficiency is reduced when operated at 70 to 100 kPa. Also, they are forced to disperse water in large droplets, which may result in runoff and soil sealing (Li *et al.*, 2019).

When impact sprinklers are operated in low-pressure conditions, water is spread unevenly, leading to water loss. To maximize water distribution under low-pressure conditions, it is necessary to break up the jet mechanically with a fixed water dispersion device. Low-pressure sprinklers can be improved in a number of ways by adding fluidic devices, orifice nozzles, non-circular nozzles, vanes, and more. In recent years, technological advancements have led to the widespread adoption of rotating spray plate sprinklers (RSPSs), which have a spray plate with grooves that rotate under the force of a water jet (Figure 3). These sprinklers are used in irrigation machinery because their varying plates allow for a variety of droplet sizes and spray patterns (Faci *et al*., 2001; Hanson and Orloff, 1996; Liu *et al*., 2017).

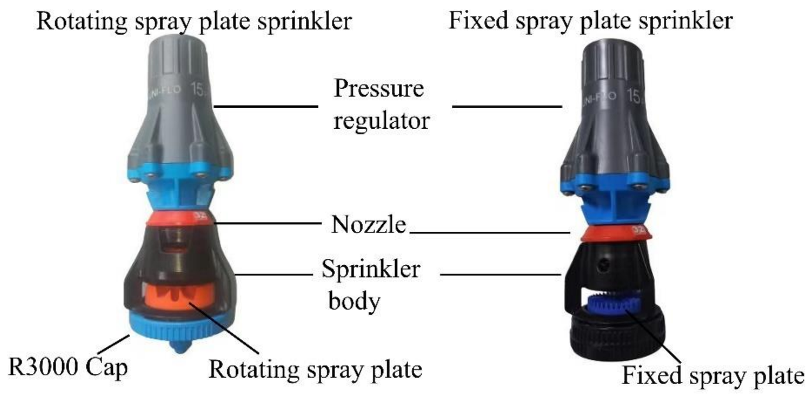

Figure 3. Low-pressure spray plate sprinklers of Nelson Irrigation.

The fluidic sprinkler is an innovative sprinkler head. It operates on the Coanda Effect principle, in which water flows from the nozzle into a tube fitted in the fluidic component to create a low-pressure area with a simple design, low energy loss, and low cost. Numerous studies have been conducted to improve the hydraulic performance, stability, and reliability of fluidic sprinklers in windless conditions (Li *et al.*, 2011; Zhu *et al.*, 2012). There are still issues with the fluidic sprinkler's uniform rotation, even though this application enhanced the water distribution.

Low-cost sprinklers retain the advantages of conventional sprinklers while eliminating the factors that kept small farmers from using them, including the required amount of pressure and expense and the intricacy involved in their use and maintenance. Effective water loss reduction requires careful sprinkler selection in addition to improved crop, soil, and climate management. With the purpose of making the selection of pivoting sprinklers more effective, a runoff-potential index was developed (Hasheminia, 1994; Luz and Heerman, 2005; Rogers *et al.*, 2017).

Pivoted sprinklers can improve water distribution by controlling evapotranspiration, which varies according to the crop type, irrigation method, climate, and soil condition. Low-pressure sprinkler systems that apply water within or near the crop canopy may consume less energy and result in less evaporation, but may be less effective due to runoff. To make it easier to select moving spray-plate sprinklers for center-pivot and lateral-move sprinkler irrigation systems, King (2016) developed a quantitative, soil-independent runoff potential indicator. Many commercially available sprinkler packages were used to evaluate the approach, revealing significant variations that show the runoff potential of several packages might be similar. A runoff index is a valuable tool for comparing different types of sprinklers, indicating which one possesses large droplets and small wetted diameters.

Fertigation in sprinkler irrigation

Chemigation refers to the practice of applying several chemicals to a crop by means of irrigation. When using sprinkler irrigation, fertilizer is dissolved, dispersed, and sprayed into the air by a nozzle with water. Many different types of chemicals, including fertilizers, pesticides, insecticides, fungicides, herbicides, nematicides, and growth regulators may be used (Johnson *et al.*, 1986; Threadgill, 1985). On the other hand, the most prevalent type of chemigation involves the injection of water-soluble fertilizers (Bar-Yosef, 1999; Holzapfel *et al*., 2009; Kant and Kafkafi, 2013).

Since the early 1950s, fertilizers have been applied through irrigation in greenhouses in the Netherlands. At the same time, US farmers started small-scale trials incorporating fertilizers like ammonium nitrate and gaseous and liquid ammonia in surface, flood, and furrow irrigation systems. Micro-irrigation was developed and put into practice at the same time that fertigation technology advanced in Israel in the early 1960s. For the precise application of nutrients, electrical pumps and mixing tanks were developed. In the early stages, the distribution of nutrients through fertigation exhibited a certain degree of unevenness, particularly in cases where fertilizer tanks were employed. Subsequently, a greater degree of uniformity in distribution was attained by the utilization of venturi suction pumps and fertilizer injectors.

Micro-irrigation systems and fertigation will continue to become more popular due to their numerous advantages. Fertigation allows the timely application of the appropriate fertilizer dosage, resulting in minimal environmental impact while reducing the amount of the fertilizer by 25–50 %. The precise application of fertilizers directly to the root zone results in efficient fertilizer use and reduced nitrogen leaching below the root zone. Fertigation also saves energy and labor costs associated with fertilizer application (Shukla *et al*., 2018; Ranjan and Sow, 2021). Some good fertilizers commonly used for fertigation are listed below (Table 1).

Table 1. Fertilizers suitable for fertigation.

Nutrient	Fertilizer
Nitrogen (N)	Urea, ammonium sulphate, urea ammonium nitrate (liquid), ammonium nitrate
Nitrogen and phosphorus (N and P)	Mono ammonium phosphate, urea phosphate
Phosphorus (P)	Phosphoric acid
Phosphorus and potassium (P and K)	Mono potassium phosphate
Potassium (K)	Potassium chloride, potassium sulfate, potassium nitrate, potassium thiosulphate
Magnesium and calcium (Mg and Ca)	Magnesium nitrate, calcium nitrate

Fertigation improves crop production management. In 1999 and 2000, a study was conducted in an acid sulfate soil in central Thailand to investigate the impact of various nitrogen (N) fertigation rates on maize yield and nitrate leaching. There were four nitrogen fertigation treatments, i.e., 0, 100, 150, and 200 kg N ha^{-1}, each with three replications set up in a randomized complete block design. The source of nitrogen was urea. The results demonstrated that a fertigation system can be a successful and novel way to deliver water and plant nutrients simultaneously to a crop (Asadi *et al.*, 2002).

China uses more than 60 million Mg of fertilizer annually, one-third of all fertilizers used worldwide. However, the fertilizer use efficiency in China is only 30 % because of excessive application rates and outdated fertilization technologies (Tang *et al.*, 2019), severely hindering the sustainable development of agriculture. Fertigation has gained popularity in China since 2010 due to its numerous benefits. Among the current sprinkler irrigation projects, it is estimated that more than 20 % of sprinkler-irrigated land uses fertigation.

To provide technological support for the widespread adoption of fertigation in center-pivot irrigation systems and to evaluate fertilization uniformity, a fertilizer injection device with a plunger pump was developed. Field experiments were conducted on a system fitted with a fertilizer injection device (Yan *et al.*, 2015). In the meantime, field tests were conducted to find the optimal method for controlling water and nitrogen for wheat, maize, and potato (Cai *et al*., 2018; Li *et al.,* 2018; Zang *et al.,* 2018). Zhang *et al*. (2018) studied water and fertilizer evaporation and drift losses in a center-pivot irrigation system through field experiments. Recently, the Chinese government has been encouraging the development of integrated crop-livestock production systems that use sprinkler irrigation to apply the processed liquid waste of livestock to the field. However, there are still several significant concerns with this technology, like agricultural non-point source contamination, heavy metal residues in crops, and inadequate standards (Dong *et al.*, 2019).

Water-pesticide integration technology

Water and pesticide integration technologies can efficiently solve water and pesticide use in agriculture while also supporting high-yield agricultural farming. Pesticide irrigation has several benefits, including reduced pesticide use, increased crop production and quality, and a better soil environment. Water and pesticide integration is one of the most valuable water-saving irrigation technologies in China due to its high effectiveness and time management (Liu *et al.*, 2016; Prabakaran *et al.*, 2018; Zhu *et al.*, 2016).

Researchers have worked to develop and optimize an integrated sprinkler irrigation system for the application of pesticides. Tsaboula *et al.* (2016) used a particle image velocimeter and variables such as working pressure and nozzle diameter to investigate spraying outflow and discovered changing rules for the outflow field, droplet velocity, and spray angle. Guler *et al.* (2020) evaluated the effects of varying wind speeds on droplet accumulation for five different orifice sizes used in rotary micro sprinkler nozzles in orchard systems. The results showed that the rotational micro sprinkler nozzles created medium to coarse droplets, which might be employed to reduce spray drift while maintaining pesticide efficiency.

Micro-sprinklers are important components of integrated water and pesticide technology, and their hydraulic performance has a significant impact on the quality of water-pesticide integrated irrigation systems. Wang *et al.* (2022) developed an integrated micro-sprinkler and investigated how the structural parameters affected irrigation and pesticide spraying performance. Using single-factor and three-factor four-level orthogonal tests, the structural optimization of the sprinkler was evaluated. The irrigation flow rate, wetted radius, and uniformity coefficient were used to evaluate the performance of the sprinklers, while the flow rate, spray cone angle, and relative droplet size range were used to assess the performance of the pesticide sprayer. The results of this study offer a theoretical basis for the practical application of sprinklers. Liu *et al.* (2023) designed a water-pesticide integrated micro-sprinkler irrigation system for grape plantings on flat frame installations. Under low pressure, it can irrigate crop roots; under medium pressure, it can apply pesticides to the crop leaves. The flow field of the micro sprinkler was simulated using computational fluid dynamics software to find out the influence and change in main structural parameters. In their study, the structural parameters for the micro sprinklers were optimized. Several operating pressure levels were used to compare the hydraulic performance of the optimized and original sprinklers.

Smart irrigation technologies

Smart irrigation controllers save water by monitoring and analyzing data regarding site conditions such as soil moisture, rain, wind, slope, soil, and type of kind. Based on these parameters, the controllers deliver the right amount of water (Dukes, 2009). Smart sprinkler technologies (Figure 4A) are the latest development in the field of

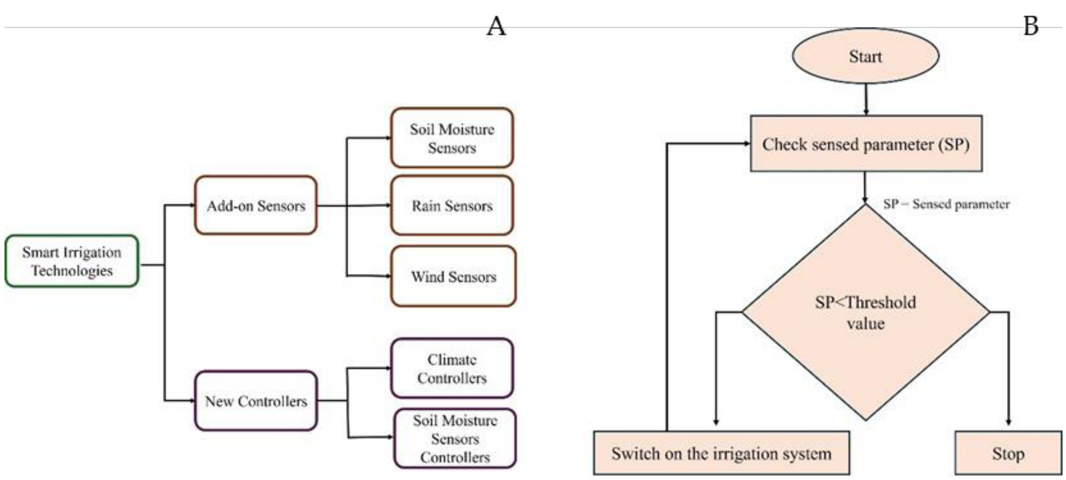

Figure 4. A: Smart irrigation technologies; B: working mechanism of a microcontroller (Difallah *et al.*, 2018).

irrigation. In essence, they collect feedback from the irrigation system and schedule or alter the duration and frequency per that information (Gotcher *et al.*, 2017). Smart controllers plan irrigation based on landscape and weather to avoid overwatering and runoff. The working flowchart of the microcontroller is shown (Figure 4B) (Difallah *et al.*, 2018).

According to the findings of two demonstration studies in California utilizing evapotranspiration (ET) controllers, some irrigation savings are possible, but more extensive comparisons are needed. ET controllers can change irrigation in response to plant needs (Dukes *et al.*, 2009). Similar to ET controllers, soil moisture controllers can decrease irrigation while maintaining turfgrass quality. Soil moisture controllers saved 72 % of irrigation and 34 % of water, compared to homeowner irrigation schedules. A rain sensor stops an automatic sprinkler system from turning on during and after a rainstorm. The rain shut-off gadget stops irrigation when it detects water, and irrigation restarts after the evaporation of rainwater from the sensor. Rain sensors are important devices for preventing wasteful irrigation (Cardenas-Lailhacar *et al.*, 2010).

Kumar *et al.* (2013) investigated a prototype of intelligent irrigation system that uses microcontrollers. It allows irrigation to occur in areas that need watering while avoiding areas where adequate soil moisture is indicated. The pesticide sprinkling system was another highlight of this prototype; it automatically prepares the mixture in the proportions necessary for the plants and minimizes human error. Low-cost sensors and basic circuitry make this tool affordable.

Another project conducted by Ismail *et al.* (2019) focused on the development of a smart irrigation system based on Internet of Things (IoT) technology. The primary objective was to regulate and manage water consumption. This irrigation system was made up of a few sensors, including soil moisture, humidity, and pressure sensors used to monitor soil conditions. To increase sensitivity, these sensors were also connected to the internet via a Wi-Fi module. The users can supervise the irrigation system through the report displayed from the mobile application, which displays sensor readings and controls the water pump in emergencies. The project met its goals for water consumption, minimal project cost, less labor cost, minimum power usage, and reliability.

Islam *et al*. (2020) proposed a model of an IOT-based smart irrigation system in agriculture and used a variety of sensors to monitor the temperature, humidity, pH, and water level in agricultural fields. The data from the sensors was transmitted via wireless transmission to a web server database, and the irrigation system was operated using a smart irrigation mobile application.

Variable rate irrigation technology

Sprinkler irrigation systems can apply water and fertilizers precisely. Manually operated systems require labor for their intended operations. Moreover, it is challenging to irrigate based on real-time crop water requirements (Bitella *et al.*, 2014; Elshaikh *et* *al.*, 2018; Semananda *et al.*, 2018). The water application rate varies both spatially and temporally based on the actual crop water requirements (Cambra *et al.*, 2018; El-Chami *et al.*, 2019). Hence, to achieve the objectives of precision agriculture, it is important to evaluate the crop water requirements, establish proper irrigation scheduling, and regulate the application process to ensure that only the required amount of water and nutrients are applied.

Precision irrigation should integrate modern techniques and application methods with sophisticated modeling/simulation, sensing, and control technologies to achieve its optimal performance (Baruah *et al.*, 2024; Chauhdary *et al.*, 2023). The physical infrastructure that conveys the water to the crop and the controls that run and manage the system are the two major components of precision irrigation. Data collection is the first step in the management system, and various sensors and instruments are used to obtain precise information about the crop, soil, and weather. The next step is data interpretation, which involves using different modeling and simulation software to predict crop behavior in response to various applications. After this, field irrigation is done based on crop water requirements, and finally, the agronomic, engineering, and economic performance of the system is evaluated (Anjum *et al.*, 2023).

Variable rate irrigation (VRI) is a technique that provides water to the crop precisely at the right time and place to improve water use efficiency and production, save energy, and reduce nutrient leaching (Pan *et al.*, 2013). A very basic form of VRI provides speed control, which adjusts the amount of water applied by changing the lateral's speed as it moves over the field. This strategy can yield the advantages of full VRI in certain cases while being more cost-effective and less difficult (Evans *et al.*, 2012).

Center-pivot and linear-move sprinkler machines are widely used as pressurized irrigation systems worldwide and have a high irrigation efficiency potential (Faci *et al.*, 2001). Farmers use these sprinkler irrigation systems because they cover a large area and have a high level of automation; therefore, they are most suitable for variable application rates (Evans *et al.*, 2012). Hedley and Yule (2009) studied the comparison between VRI and conventional irrigation methods and found that VRI saved 9–19 % more irrigation water. In 2018, a sprinkler prototype with a novel concept of an iris mechanism for variable-rate sprinkler irrigation was developed in Brazil. The suggested approach allows flow rates to be obtained closer to the required values, providing better flexibility and accuracy in applying the target irrigation depth (Sobenko *et al.*, 2018).

VRI systems regulate the center-pivot's travel speed and the duty cycle of solenoid valves placed in front of each sprayer. A control device with a geo-recognizer, like a global positioning system (GPS) unit, is used to locate specific sites and establish unique irrigation zones. The system may apply VRI to center-pivot irrigation systems in both the radial and circumferential directions by altering the pivot rotation speed (Zhang *et al.*, 2018). The uniformity of sprinkler irrigation in each management zone directly impacts crop growth and production. Using a linear-move sprinkler irrigation system with different nozzle diameters, VRI can be readily and economically achieved.

Liu *et al.* (2021) developed a variable rate irrigation uniformity model for linear-move sprinkler irrigation systems. The sprinkler uniformity under various circumstances can be predicted using this model for any linear move irrigation system.

VRI entered commercial production with a sprinkler hardware control system that enhanced control accuracy and reduced expenses. Examples of proper VRI prescriptions that hindered the promotion and deployment of the technology are management zone demarcation, which is mainly determined by soil available water content (AWC) and soil electrical conductivity (EC) (Sui and Yan, 2017; Zhao *et al.*, 2017), and the irrigation decision support system. Direct or indirect attention is paid to the soil in both AWC and EC techniques. However, irrigating the crop rather than the soil is the primary purpose of irrigation.

DISCUSSION

For the precise application of nutrients and water, the present work refers to cutting-edge and innovative sprinkler irrigation technologies. In addition, to save water and energy, sprinkler irrigation equipped with advanced technologies can precisely apply the required amount of water, fertilizers, and other chemicals to the crops. It is possible to reduce energy costs by substituting low-pressure sprinklers with high-pressure sprinklers. As high-pressure impact sprinklers require a minimum operating pressure of approximately 300 kPa, when the operating pressure is increased from 400 to 450 kPa, energy costs increase by up to 18 % (Sheikhesmaeili *et al.*, 2016). Low-pressure sprinklers require 65–175 kPa for effective operation, resulting in lower energy costs without compromising the flow rate.

Fertilizers can be applied effectively through sprinkler irrigation, saving 25–50 %. Similarly, water-pesticide integration technologies in sprinkler irrigation have several benefits, including reduced pesticide use, increased crop production and quality, and a better soil environment. Smart irrigation controllers save water by monitoring and analyzing data regarding site conditions such as soil moisture, rain, wind, slope, soil, plants, and more. Based on these parameters, these controllers deliver the right amount of water at the right time. VRI is a technique of precision agriculture that allows the application of water to crops at a desired location based on actual crop water demand. It is clear that information and results evaluation will enable students and researchers to generate new ideas for future innovations in the field of water-saving irrigation techniques, as well as improvements in the design of existing sprinkler systems.

Sprinkler irrigation is a water-saving technology that promotes green agriculture and improves water productivity. Some factors should be considered for the future promotion of sprinkler irrigation technologies. Although sprinkler irrigation offers excellent uniformity, controllability, and easy operation and maintenance, regional compatibility is a major issue. It is essential to select the appropriate sprinkler system depending on regional conditions. The development of high-uniformity sprinkler fertilizing equipment and control systems is also essential. Multifunctional equipment that applies water, fertilizer, and pesticide simultaneously is critical to maximizing operational efficiency.

It is recommended to use information technology, such as rainwater irrigation systems and crop water collection equipment with high control precision, intelligence, dependability, ease of use, and wired or wireless sensor network technology. As part of an integrated water, fertilizer, and pesticide irrigation control system, variable irrigation devices, water supply, positioning devices, and control devices should be considered. Developing solar and wind-powered sprinklers should be prioritized for regions with abundant sunshine and plentiful wind energy, respectively.

CONCLUSIONS

This study looked into the major emerging technologies in sprinkler irrigation systems and their significance in conserving water and increasing agricultural yield. To cover investment costs, it is critical to prioritize irrigation engineering and research, incorporating new technologies that build on prior knowledge and aim to maximize crop yield. Although the application technology has been established for many years, one of the outstanding research areas in sprinkler irrigation is the development of an optimal approach for irrigation scheduling.

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