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Smart Irrigation Solutions for Today's Farms

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1. Introduction

Agricultural systems in Arizona face numerous challenges due to drought, groundwater depletion, and increasing competition for water from industrial and urban sectors. Water districts across the state must adhere to strict regulations regarding reduced water allocations, which adds pressure on growers to sustain crop productivity with limited water supplies (Elshikha et al., 2024). These challenges are further exacerbated by the impacts of climate change, which increases the risks of water shortage in arid regions (Elsadek, 2023).

Automated irrigation systems employ technology to monitor, control, and adjust irrigation processes without constant human intervention, offering numerous benefits. Moreover, it optimizes water use by adjusting schedules and flow rates based on real-time data from sensors, reduces the need for labor, promotes crop health, and yields cost savings over time (Elsadek, 2018). However, transitioning to automated irrigation necessitates selecting suitable technology and integrating it with existing systems, including sensors, controllers, communication systems, and user interfaces. This publication aims to explore the potential of automated irrigation tools and their management across drip, sprinkler (center pivot and linear systems), and automatic gated surface irrigation systems. It will provide valuable insights to enable growers to understand the potential of automated irrigation systems better and implement these advanced systems effectively. Implementing automation in irrigation holds the promise of transforming farming operations, ensuring sustainability, productivity, and success in an ever-evolving agricultural landscape.

2. Overview and automation options

2.1. Drip Irrigation

Drip irrigation is a precision irrigation method that delivers water directly to the root zone of plants, minimizing water waste and ensuring optimal soil moisture levels. Drip irrigation started long ago in Ancient China, where farmers used buried clay pots filled with water to irrigate plants slowly. Then, in the 1860s, German researchers began testing clay pipes placed just under the soil to water plants, a system that combined drip irrigation and drainage (https://bluejayirrigation.com/history-of-drip-irrigation, last accessed on November 07, 2024).

In the 1930s, Simcha Blass (https://en.wikipedia.org/wiki/Simcha_Blass, last accessed on November 7, 2024) noticed a tree thriving without a visible water source. Blass discovered that a leaking pipe near the tree delivered a slow, steady water drip to the tree's roots. This observation led Blass and his son Yeshayahu to develop methods for efficiently and directly providing plant water. In the early 1960s, the Blasses developed a system that utilized plastic tubing with small emitters designed to release water slowly and at a controlled rate. This innovation addressed clogging issues and uneven water distribution, leading to the establishment of Netafim in 1965. Symcha and Yeshayahu Blass pioneered the commercial production and application of drip irrigation systems and established industry standards.

2.1. Drip Irrigation

Automation in drip irrigation systems enhances efficiency by allowing systems to operate according to a program defined by the grower in a controller. Automated drip irrigation systems can function without manual intervention, ensuring consistent and precise water delivery and saving on labor costs. Automation in drip irrigation began in the 1980s with basic timers and controllers used to schedule irrigation events. As technology progressed, automation in drip irrigation systems advanced, with the primary aim of automating water application through drip systems with automated controllers, control valves, and filtration units (Figure 1).

Figure 1. Automated disk filtration unit. (Credit: Netafim Corporation. Used by permission)

2.2.1.1. Remote monitoring systems

Remote monitoring systems further enhance the efficiency gains achieved through automation. Early examples of remote monitoring included soil moisture sensors, followed by various sensors such as weather stations, leaf wetness sensors, and dendrometers, which measure changes in a tree's trunk size. As the tree takes in water, its trunk expands, and as it dries, it slightly shrinks. By tracking these changes, dendrometers reveal the tree's growth, health, and water status.

Modern remote monitoring systems, including sensors and data analytics, provide real-time insights into field conditions and increasingly accurate data on soil moisture content, water flow rates, and climatic conditions. This information is critical for making informed irrigation decisions. Integrating remote monitoring with automation technologies into drip irrigation systems significantly improves water use efficiency, crop yield, and agricultural productivity. Combining monitoring with automation helps ensure that plants receive the right amount of water at the right place and time. Examples of the automation and monitoring tools utilized for drip irrigation systems are the following:

1. Automated controllers: These controllers utilize data from soil moisture sensors, flow meters, and weather stations to schedule and control irrigation. They can be programmed to activate or deactivate based on predefined soil moisture thresholds or weather conditions, ensuring water is applied only when necessary.
2. Soil moisture sensors: These sensors maintain optimal soil moisture levels by continuously monitoring the soil moisture content. The data obtained can be used to adjust irrigation schedules and amounts, reducing water waste and preventing over-irrigation, which can lead to water and nutrients leaching below the root zone and soil degradation.
3. Flow meters: Flow meters measure the volume of water delivered to different zones in the irrigation system. By tracking water use, farmers can identify inefficiencies such as leaks or blockages in the system, enabling timely maintenance and reducing water loss.
4. Weather stations: Weather stations provide critical data on temperature, humidity, rainfall, and wind speed. This information is used to calculate reference evapotranspiration, which is widely used by growers for irrigation scheduling. This ensures that water is applied when it is most beneficial to the crops.
5. Remote imaging: Satellite, airplane, or drone imaging can efficiently capture data for large expanses of ground. Thermal, multi-spectral, and red-blue-green (RGB) data deliver information that can be utilized to understand crop water status and validate the data provided by the infield sensors.

2.2.1.2. Precise water and nutrient application

Advanced controllers offer comprehensive recommendations. They combine data from automation systems (applied water), sensors (water used by the crop), and the weather data from the weather station and remote imaging (evaporation and transpiration loss), providing a complete picture of the crop, as well as the water and nutrient system application status and history. Using this comprehensive data, the operating system can make irrigation recommendations to assist the farmer in optimizing the performance of the drip irrigation system. These systems should connect to the cloud and allow the farmer to interact with the data from the office or phone, as well as allow the farmer to adjust recommended irrigation plans made by the controller. Controllers should be seamlessly integrated with pumps, filters, valves, and fertigation systems to provide 100% reliable control of the system.

2.2.1.3. Integrated solutions

Many companies offer products for automation, monitoring, or recommendations. However, the need for a comprehensive solution is increasingly evident. The standard quickly evolved into a proper irrigation and fertigation control operating system, combining monitoring, imaging, automation, and a recommendation tool. This integrated solution simplifies decision-making, making it more efficient and less complicated, which is essential in modern precision agriculture.

Integrating automation and remote monitoring technologies in drip irrigation systems offers substantial efficiency gains. By providing real-time data and enabling precise control over water application, these technologies equip farmers with the tools to use water resources judiciously, maximize crop yields, and enhance environmental sustainability. As the agricultural sector faces increasing water scarcity and changing climate conditions, adopting advanced drip irrigation systems will be crucial for sustainable and efficient management of our limited natural resources.

2.2.1.2. Precise water and nutrient application

As growers strive to maximize efficiency and sustainability, the benefits of center pivots and linear irrigation systems become increasingly apparent (Figure 2). A significant advantage of these systems is their ability to reduce water usage by minimizing evaporation and runoff, ensuring that more water reaches the plant root zone. This not only conserves water but also leads to cost savings for growers. Center pivots and linear move systems provide improved control over soil moisture levels and enhanced chemigation, fertigation, germination, and salt leaching. Through precise water application management, growers can tailor the moisture content of the soil to the specific needs of different crops. This results in healthier plants and higher yields, all while conserving water resources and fostering a more sustainable and balanced agricultural landscape.

2.2.1. Automation of sprinkler irrigation

Valley Irrigation offers innovative solutions that significantly reduce labor costs by leveraging cutting-edge automated irrigation technologies. These systems integrate seamlessly with remote devices, minimizing the need for manual intervention. Key technologies include:

1. Soil moisture monitoring systems that use advanced soil moisture sensors to provide real-time data, optimizing irrigation schedules and conserving water while reducing manual labor.
2. Automated control systems that are capable of monitoring and controlling various equipment, such as pumps, flowmeters, and weather sensors. Its remote operation potentially streamlines farm management, saving time and resources.
3. Some systems include GPS-based monitoring devices that enable precise control over the movement of irrigation systems. Automating system navigation further reduces the need for hands-on operation and increases overall efficiency.
4. Some systems include variable rate application nozzles that allow growers to tailor water application rates based on yield maps, remote sensing, and soil maps.

Figure 2. (a) Center pivots and (b) linear move systems. (Credit: Valley [Valmont] Company. Used by permission)

While center pivots already reduce labor costs by several times over manually operated surface irrigation, the integration of automation and precision ensures greater profitability and sustainability for modern agricultural operations.

2.3. Gravity-fed surface irrigation

High-performance surface irrigation depends on the use of automation, sensor technology, science, and data analytics, real-time optimization, and irrigation scheduling methods to reduce water applied and increase yields by upgrading inefficient manually operated flood irrigation from 50-60% application efficiency to 80-90% application efficiency, increasing water efficiency in crop production by at least 20%, through the combination of the following two improvements:

1. Surface irrigation system design (high flow rates), infrastructure (irrigation automation and sensor technology) and real-time optimization of the irrigation system,
2. Irrigation Scheduling and crop water management with sensor technology, data analytics, prediction, and prescription of irrigation events with surface irrigation automation.

In many cases, productivity was also increased, significantly improving the ratio of yield/volume of water applied. In some cases, it produced double the dry matter per acre-foot of applied water.

2.3.1. Optimizing flow rates for surface irrigation

The border check bay width ratio to flow rate is an essential design criteria element. This requires replacing a number of low-flow discharge outlets with a single high-flow outlet per border check, thus increasing the discharge rate and reducing the time to cut-off, which is proven to increase Distribution Uniformity and Application Efficiency significantly. With improvements in application efficiency with surface irrigation, the applied water (using higher flow rates) ends up in the root zone, evenly distributed along the bay, resulting in losses by deep percolation and runoff being small, thus increasing water efficiency in crop production, which is not possible with low flow, manually operated, flood irrigation systems.

With improvements in real-time optimization of the surface irrigation system, applied volume to the bay is precisely controlled by a canal flow meter and continuously measured; irrigation evaluation data combined with flow depth measurements during an irrigation event pre-calculates time to cutoff early within the wetting advance (25% to 50% along the bay) and automatically adapts the irrigation program to increase or decrease time of the bay gate opening to significantly reduce run-off and deep percolation, resulting in higher water efficiency gains.

2.3.2. Surface irrigation automation

Automation for surface irrigation achieves the benefits of high flow rates and shorter run times, which are essential for attaining High-Performance surface irrigation. This involves installing remotely operated valves or gate actuators (for border check) on high-flow bay outlets, an on-farm radio communication network, and web-based cloud computer software, which is used to manage all aspects of irrigation on the farm (Figures 3 and 4).

A software can precisely execute automated irrigation schedules, monitor irrigation programs in progress, determine remaining runtime for the current bay, and receive management alerts.

Although surface irrigation has been a manual process for the last 6,000 years, it can be automated with new automated surface irrigation systems. Schedules can be checked graphically to ensure correct sequence and spatially to ensure each bay that is intended to be irrigated is included in the irrigation program. Once an irrigation program is set up and checked by the grower, the control system triggers irrigation to

Figure 3. An automated bay outlet for border check surface irrigation. (Credit: Rubicon Water. Used by permission)

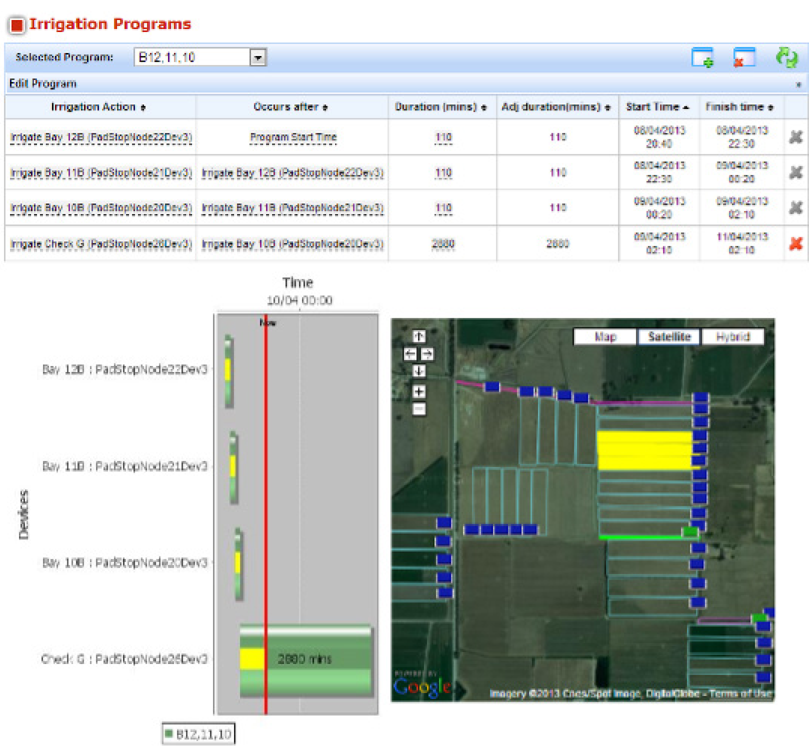

Figure 4. The interface for an automated surface irrigation controller. (Credit: Rubicon Water. Used by permission)

each of the gate's radios. Progress of an irrigation program can be monitored remotely to ensure each bay is being irrigated at the instructed time slot and its status is indicated as completed or in progress.

By modernizing inefficient flood irrigation systems to high-performance surface irrigation systems, irrigators can gain similar application efficiencies, increase yields, and lower labor costs while capitalizing on the energy-free, gravity-fed water supply. Thus, zero greenhouse gas emissions can be maintained with an on-farm irrigation application system using surface irrigation.

2.4. Mobile drip irrigation (MDI)

Mobile Drip Irrigation (MDI) systems attach drip tubing to center pivot systems (Figure 5). The first ideas and concepts were developed by Rawlins in 1974 with the implementation of a commercial working system by Dragon-Line, LLC.in 2015 (Coelho et al., 2022). The MDI system can reduce foliar wetting, salt damage, and spray evaporation. Moreover, it is considered to be one of the most efficient irrigation methods (Molaei et al., 2020).

MDI combines the high efficiency of surface drip irrigation with flexibility, lower hardware costs, and convenience of center pivot irrigation. In this system, the drip tubing is attached to center pivot irrigation systems to apply water directly to the soil surface. The driplines are dragged across the field to create a uniform wetting pattern across the irrigated area. MDI will reduce the use of fungicides and chemicals because foliage stays dry. Fertilizers are precisely delivered to the surface of the soil. Wheel tracks and muddy tires do not exist in the field, reducing wear and tear on pivot drivetrains. Precision germination can be achieved without watering the soil surface, reducing weed pressure for organic farming

Dripper lines can be spaced from 12″ to 60″ and connected to a manifold suspended by a cabling system. The system utilizes a winch assembly at each tower to allow flexibility of moving manifold right or left up to 30″ and to raise ground clearance from 4 ft to 9 ft. Special developed 2-GPH emitters are embedded eternally into a 0.5″ x 50 mil polyethylene tubing that is pressure-compensating and self-flushing every 6 inches. Specialized flow printouts are produced to attain a 90% or greater application emitted to the soil in predetermined precise placement. A specially designed flexible hose is now used to extend from the manifold to the surface before dripper lines are attached. The 0.5″ hose is non-kinking, which flexes to allow reversing without tangling or blowing into wheel track areas.

2.4.1. MDI Enhancing Technology

MDI enables the producers to gain precise irrigation for precision farming. Whether flood or pivot irrigation, MDI will precisely deliver the prescribed application to the soil so precision soil probes and moisture measuring devices can be trusted. MDI will provide the same amount of water each time regardless of wind, evaporative losses, runoff, field topography, or soil type. Soil sensors, soil probes, infrared devices, and other technologies will be able to provide more accurate reports because the water being applied will be precise and dependable. For example, if the wind is blowing with traditional sprinkler nozzles, growers may get only a 60% accurate reading of the soil probe. Estimated savings with MDI are expected to increase water efficiency compared to flood irrigation.

2.4.2. Automation of MDI systems

The pivot manufacturers integrate automation into MDI systems, with additional support from soil moisture probes and water management companies. MDI systems deliver high irrigation efficiency and uniform water distribution by combining drip technology with center pivot and linear systems, further enhanced through automation. The pivot control panel allows precise application rate adjustments and speed, ensuring accurate delivery of fertilizers and chemicals.

Figure 5. (a) Schematic of mobile drip irrigation system (MDI) design, (b) Using MDI for corn and alfalfa crops. (Credit: Dragon line. Used by permission)

This approach ensures targeted placement into the soil while minimizing interference from wind or crop foliage. Options are available to winch manifold line spacing horizontally right or left up to 15 inches to germinate seeds and then move over to avoid damage to small plants. The owner can switch from mobile drip irrigation to the original sprinkler nozzle head operation for certain operations.

3. Conclusion

Automated irrigation systems allow farmers to access real-time data and make better decisions about irrigation amounts and events. For instance, automation of pressurized drip systems has significant advantages, allowing for precise, on-demand irrigation scheduling. This level of automation reduces the need for manual intervention, increases water use efficiency, and minimizes the risk of over- or under-irrigation. Modern center pivots and linear irrigation systems have also been improved by implementing advanced automatic devices to help growers better control their water use and grow more crops with water-saving strategies. The current center pivots and linear systems (Low Elevation Spray Application-LESA and Low Energy Precision Application-LEPA) can reduce water loss from evaporation and runoff. Other technologies, such as mobile drip irrigation, enable precise watering adjusted to the needs of various crops by combining the functionality of a sprinkler system during germination with drip irrigation for subsequent growth stages. Improvement of gravity-fed surface irrigation using sensors and controllers with automated gates has also enhanced the efficiency of this irrigation method, attracting more enthusiastic growers who wish to keep their traditional systems in place. Additionally, automated systems such as filtration units help prolong the durability of the irrigation system.

These advanced irrigation technologies will help growers manage water efficiently, increase crop yields, and ensure agriculture sustainability in the face of climate change and water shortages, especially in the US Southwest.

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