

# Climate Smart Irrigation Technology: A Boon to Plants, People and Planet

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In the era of smart technology and world with changing climate, agriculture has grown to Climate smart agriculture (CSA) is often defined as “agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces or removes greenhouse gases where possible and enhances achievement of national food security and development goals” (FAO, 2013). A vital part of this approach is Climate-Smart Irrigation (CSI), which involves implementing irrigation strategies suited to specific agro-climatic and social conditions, while considering both the challenges and opportunities brought about by climate change.

CSI is built on the three core pillars of CSA: enhanced productivity, climate adaptation, and mitigation. It focuses on improving yields and incomes from irrigated farming systems, not only at the farm level but also along the entire value chain, while avoiding environmental harm and safeguarding the rights of other water users across space and time. CSI helps reduce farmers vulnerability to short-term climate shocks and long-term stresses by building adaptive capacity. Additionally, it works to lower greenhouse gas emissions associated with each unit of agricultural output whether food, fibre, or fuel produced through irrigation. This can be achieved by minimizing the use of non-renewable energy sources for water pumping and treatment, promoting solar-powered systems, reducing agrochemical inputs, and managing both soil and irrigation infrastructure in ways that enhance carbon sequestration.

## CSI for plants, people, and planet

Conventional irrigation methods often result in excessive water use, soil damage, and reduced agricultural productivity. These challenges are being intensified by the effects of climate change, making the shift towards climate-smart irrigation (CSI) critical for ensuring sustainable farming, conserving water, and adapting to changing climatic conditions. CSI utilizes advanced methods and smart technologies that improve the water use efficiency, minimize losses, and boost crop tolerance to environmental stress. Climate smart irrigation systems are designed to meet the specific needs of crops throughout their development by delivering water and nutrients accurately at the right time, in the right place, and in the right amount by eliminating waste. This precise approach supports healthy plant growth, resulting in higher productivity and better use of available resources. With CSI, farmers can improve profitability by

producing more and higher quality crops per unit area while reducing the inputs of water, energy, and fertilizers. By adopting precision irrigation, farmers gain better control and consistency in crop performance, even under uncertain weather conditions. This not only increases yields but also enhances return on investment (ROI). Moreover, CSI contributes to build climate resilience in agriculture by preventing the overuse of groundwater, reducing the risks of soil erosion and waterlogging, and lowering energy requirements due to more efficient water management. Ultimately, this approach allows farmers worldwide to meet rising food demands, without depleting natural resources helping to secure food systems and protect the environment for future generations.

## Practices and Technologies in Climate Smart Irrigation System

### Precision Irrigation

Precision irrigation involves delivering water to crops in a highly controlled and accurate manner, aiming to maximize water use efficiency and boost crop productivity while reducing unnecessary water use. This approach relies on modern technologies such as soil moisture sensors, weather stations, and satellite imagery to monitor environmental conditions, soil water levels, and agricultural plants viability. Automated control systems actively modify irrigation practices by utilizing real-time data, thereby enhancing the efficiency of water distribution. Precision irrigation includes a range of techniques and tools, each designed to meet specific crop and field requirements for optimal water management.

### Drip Irrigation

Drip irrigation is an advanced method of water application that focuses on delivering moisture directly to the plant's root zone at a slow and constant rate using a network of pipes, tubing, and emitters. This targeted approach ensures efficient water use and significantly reduces losses due to evaporation or runoff. Compared to traditional flood irrigation, micro-irrigation systems like drip irrigation can conserve up to 35%-65% more water, while also contributing to notable improvements in crop productivity. Studies indicate that integrating drip irrigation with effective agronomic practices can boost yields of crops like tomatoes, onions, and maize up to 130%, showcasing the technology's

exceptional potential to enhance productivity and resource efficiency.

### **Sprinkler irrigation**

Sprinkler irrigation mimics natural rainfall in which water is distributed evenly over the crop surface or soil through a pressurized system. In this method, water is delivered using high-density polyethylene (HDPE) pipes, which significantly reduce losses due to seepage and evaporation, commonly seen in traditional surface irrigation via open canals. Modern sprinkler systems are increasingly being integrated with smart technologies, offering enhanced precision, automation, and reliability. These systems utilize sensor networks both wired and wireless alongside tools that collect data on crop water requirements. Intelligent sprinkler irrigation setups also include features for remote monitoring, data transmission, automated decision-making, and control operations. To achieve such advanced functionality, the systems incorporate devices like flow meters, solenoid valves, precision regulators, and even robotic components, all aimed at optimizing water application and improving system efficiency.

### **Surface irrigation**

Surface irrigation is one of the oldest and most traditional methods of watering crops, where water is applied directly over the land surface to provide moisture to plants. This method includes various techniques such as furrow, border, basin, and check irrigation. Compared to sprinkler or micro irrigation systems, surface irrigation typically operates at lower pressure, making it more energy efficient in certain contexts. To modernize and enhance efficiency in surface irrigation, smart irrigation scheduling technologies like Supervisory Control and Data Acquisition (SCADA) systems have been introduced. These systems allow centralized management of irrigation schemes, offering greater control, monitoring, and automation. SCADA setups typically consist of components such as field devices, programmable logic controllers (PLCs), remote terminal units (RTUs), communication infrastructures, host software, and integration with third-party platforms. This networked system reduces the need for manual intervention, enabling efficient and user-friendly irrigation management with minimal effort. SCADA systems support real-time data tracking, remote or automated system control, issue detection, and the generation and storage of irrigation-related data for future analysis.

### **Climate smart Rice irrigation: AWD irrigation Techniques**

Alternate Wetting and Drying (AWD) is a sustainable irrigation method used primarily in irrigated lowland rice cultivation, particularly across Asian countries.

This technique involves supplying water to the rice field only after the previously ponded water has fully infiltrated, allowing the soil to undergo cycles of drying and re-flooding. Unlike the traditional practice of maintaining continuously flooded fields, AWD strategically manages irrigation to reduce both water usage and greenhouse gas (GHG) emissions. By allowing intermittent drying, AWD significantly lowers the volume of irrigation water required typically by 25–38% without negatively affecting crop yield. In fact, it can even enhance grain production compared to conventional continuous flooding. Moreover, AWD has proven effective in mitigating environmental impacts by reducing methane emissions by approximately 57–78%, making it a key component of climate-smart agriculture in rice farming.

### **Precision mobile irrigation**

Precision mobile irrigation, often referred to as robotic or automated irrigation, is an advanced alternative to traditional stationary irrigation systems. This innovative method utilizes mobile units outfitted with technologies such as GPS, sensors, and data processing tools to accurately apply water, where and when it is needed. By actively responding to variations in field conditions, precision mobile irrigation ensures efficient water use and improved crop performance. Nations like the Netherlands, recognized for their progressive agricultural technologies, have successfully adopted this approach to boost productivity while conserving valuable water resources.

### **Weather-Based Irrigation Scheduling:**

Smart irrigation scheduling incorporates various approaches such as plant-based, soil-based, and weather-based methods (Fig. 1) to efficiently manage water use in agriculture. Among these, weather-based irrigation scheduling stands out for its ability to adjust irrigation timing based on climatic data and weather forecasts. This method relies on weather sensors that track key factors influencing evapotranspiration, such as temperature, humidity, wind speed, rainfall, and atmospheric pressure. These sensors are typically installed in the field as part of an automated weather station to continuously gather real-time data around the crop. The collected data are then used to estimate crop water requirements through evapotranspiration models. Irrigation is triggered after a set level of evapotranspiration has been reached, with thresholds tailored to factors such as soil type, crop species, and developmental stage.

In addition to these advanced technologies, traditional water-saving practices such as mulching, cover cropping, rainwater harvesting, and water reuse and storage also holds good significance in adapting the climate vulnerability.



**Fig.1: (a) soil sensors for irrigation scheduling, (b) plant sensor for detecting sap flow in plant stems, (c) ATMOS 41 for weather monitoring (source: Bwambale et al., 2023)**

### Automation in irrigation

Automation in irrigation refers to operating irrigation with little or no manual intervention apart from surveillance. Automation systems optimize irrigation timing, frequency, and amount. Key technologies driving smart irrigation automation include communication systems, decision support tools, and cloud-based platforms. Communication technologies such as wireless sensor networks and the Internet of Things (IoT) enable real-time data exchange and remote control, making intelligent irrigation management possible (Obaideen et al., 2022).

### Wireless sensor networks (WSN)

With the advancements brought by the industrial revolution and recent progress in electronics and wireless communication, the development of low-cost, energy-efficient smart sensors has become possible. Wireless Sensor Networks (WSNs) utilize these sensors to monitor soil and crop conditions with high spatial and temporal accuracy through interconnected sensor nodes installed throughout agricultural fields. These systems enable surveillance of plant and soil, contributing to increased productivity, resource-use efficiency, and overall profitability. Effective monitoring and communication help to reduce risks due to climate aberrations, water shortages, insect infestation, and other factors unfriendly to agricultural growth and development. WSNs are helping to attain improved reaction times owing to real-time sensing and communication in agricultural contexts. There are numerous techniques for irrigation scheduling utilizing wireless sensors. Depending on the threshold levels of temperature and soil water content, the gateway permits automatic activation of the irrigation system. However, despite their benefits, the integration of certain advanced sensors, control modules, and automated valves in fixed irrigation setups can be cost-prohibitive, limiting widespread adoption in some farming systems.

### Internet of Things (IoT)

The Internet of Things (IoT) represents a modern evolution of internet technology that creates a global network connecting devices, systems, and individuals. This concept builds on earlier innovations such as embedded computing,

sensor networks, and pervasive information systems. In agriculture, IoT plays a crucial role in enabling precision farming by digitally linking various field sensors, soil monitoring devices, and intelligent tools. Through real time data collection and analysis, IoT enhances decision-making for complex agricultural tasks, including soil management, irrigation planning, and crop yield forecasting. The integration of context-aware sensors and customized hardware helps farmers manage resources more effectively throughout the entire cultivation cycle from planting to harvest. Several advanced irrigation scheduling systems now use IoT enabled platforms that combine soil moisture data and weather conditions to determine precise water requirements at specific intervals, contributing to more efficient and sustainable farming practices.

### Decision support systems

Decision Support Systems (DSS) in smart irrigation offer a structured platform that integrates various tools and methodologies to support site-specific irrigation planning and decision-making. The effectiveness and commercial viability of precision irrigation technologies greatly depend on the development of reliable and optimized DSS frameworks. Irrigation control within these systems can generally be classified into two types: open-loop and closed-loop systems.

In open-loop irrigation control, scheduling is based on fixed intervals and preset amounts of water application. These systems do not incorporate real-time feedback from field sensors, meaning they operate independently of current conditions such as soil moisture levels, plant water status, or weather data. In contrast, closed-loop irrigation systems utilize predictive models along with live feedback from field sensors to guide irrigation decisions. These models can be either physics-based, grounded in principles like mass balance and gravitational flow, or data-driven, developed from observed behaviour in real conditions. In closed-loop systems, microcontrollers analyse current field conditions and compare them to target or optimal values. Based on this comparison, control algorithms determine the required irrigation action and activate actuators accordingly. This type of control can be further subdivided into intelligent, optimal, and linear strategies, depending on the complexity and adaptability of the control mechanisms. With advancements in computational power and sensor technologies, modern DSS platforms are capable of making real-time irrigation decisions, improving efficiency, reducing water waste, and enhancing crop performance under variable field conditions.

### Cloud platforms

Smart irrigation systems generate large volumes of real-time data from various sources such as weather stations,

soil sensors, and plant monitoring devices. Managing and analysing this data requires robust storage and processing capabilities, which are provided by cloud computing platforms. These platforms receive continuous streams of information, allowing for centralized data storage, analysis, and decision-making. Several cloud platforms are commonly used in precision irrigation research and applications, including ThingSpeak, MATLAB, FIWARE, Dynamo, and MongoDB. For instance, ThingSpeak enables users to collect, visualize, and retrieve sensor data through an online interface. Microcontrollers and other IoT devices can be directly connected to these platforms, facilitating real-time data processing and control.

While climate-smart irrigation offers numerous challenges like high initial investment costs, lack of technical know-how, and limited access to technology hinder widespread adoption. Government, NGOs and private sector must work together to provide training, subsidies and infrastructure to support farmers.

### Conclusion

Climate-Smart Irrigation holds immense potential in reducing the vulnerabilities posed by climate change, particularly by ensuring efficient allocation of limited water

resources, optimizing soil moisture utilization, and minimizing nutrient runoff into surrounding water bodies. Through the adoption of these advanced techniques and smart technologies, farmers can boost agricultural productivity, lower input costs, and support long-term water sustainability. More than just a technical innovation, Climate-Smart Irrigation represents a holistic approach that nurtures plants, empower people and protect planet. As the climate crisis deepens, scaling up such approaches and practices is essential to building future where agriculture thrives in harmony with nature.

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