



POPULAR ARTICLE

Precision irrigation: The future of climate-smart water management in agriculture

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Intricacies of the subject

Water is life, and in agriculture, every drop matters. Agriculture accounts for nearly 70 per cent of global freshwater withdrawals, yet increasing water scarcity, erratic rainfall, declining groundwater levels, and climate change threaten sustainable crop production. Under these circumstances, efficient utilization of irrigation water has become one of the greatest challenges before modern agriculture. Precision irrigation has emerged as a promising climate-smart technology that enables farmers to apply the right amount of water, at the right place, at the right time, and in the right manner, thereby maximizing crop productivity while conserving precious water resources. Unlike conventional irrigation practices, which often result in excessive water application and substantial losses through runoff, evaporation, and deep percolation, precision irrigation utilizes modern information and communication technologies to supply water according to the actual crop requirement. It integrates soil, plant, and weather information with advanced decision-support systems, ensuring that irrigation is both efficient and sustainable.

What is precision irrigation?

Precision irrigation is an advanced irrigation management approach that applies water accurately according to the spatial and temporal variability of soil moisture, crop growth, and climatic conditions. The primary objective is to optimize water use efficiency, improve crop productivity, reduce production costs, and minimize adverse environmental impacts.

The concept follows the 4R principles of precision agriculture:

- **Right input:** Selecting the appropriate irrigation method.
- **Right rate:** Applying the optimum quantity of water.
- **Right place:** Delivering water directly to the crop root zone.
- **Right time:** Scheduling irrigation according to crop demand.

By adopting these principles, farmers can significantly improve irrigation efficiency while reducing wastage of water and energy.

Why precision irrigation is necessary

The increasing demand for food coupled with shrinking water resources has made efficient irrigation management indispensable.



Conventional irrigation methods frequently apply more water than crops actually require, resulting in nutrient leaching, soil degradation, groundwater depletion, and increased energy consumption.

Precision irrigation addresses these challenges by:

- Improving water use efficiency.
- Enhancing crop water productivity.
- Reducing evaporation and deep percolation losses.
- Improving nutrient use efficiency.
- Conserving groundwater resources.
- Increasing farm profitability.
- Supporting sustainable and climate-resilient agriculture.

Technologies driving precision irrigation

Recent technological advancements have transformed irrigation management from a fixed schedule to a dynamic, data-driven system.

Soil-based sensors

Soil moisture sensors continuously monitor the moisture content within the crop root zone and trigger irrigation only when required. Commonly used devices include Time Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR), and tensiometers. These sensors help avoid both over-irrigation and water stress.

Plant-based monitoring

Plants themselves provide valuable information regarding their water status. Canopy temperature sensors and indices such as the Crop Water Stress Index (CWSI) detect water stress even before visible symptoms

appear, allowing timely irrigation decisions.

Weather-based irrigation scheduling

Weather stations continuously record climatic parameters including temperature, humidity, wind speed, solar radiation, and rainfall. These data are used to estimate crop evapotranspiration (ET), which forms the basis for irrigation scheduling.

Crop water requirement is calculated using the equation:

$$ET_c = ET_o \times K_c$$

where:

ET_c = Crop evapotranspiration

ET_o = Reference evapotranspiration

K_c = Crop coefficient

This approach ensures irrigation matches actual crop water demand.

Remote sensing and GPS

Satellite imagery, drones, Geographic Information Systems (GIS), and Global Positioning Systems (GPS) enable monitoring of crop growth, vegetation health, soil moisture variability, and crop water stress across large agricultural fields. These technologies facilitate site-specific irrigation management and support Variable Rate Irrigation (VRI).

Internet of things (IoT) and artificial intelligence (AI)

IoT-enabled sensors collect real-time field data and transmit it wirelessly to cloud-based platforms. Artificial Intelligence analyzes these data together with weather forecasts and crop growth information to generate irrigation recommendations or automatically operate irrigation systems. Such smart irrigation systems reduce human intervention while ensuring optimal water application.



Climate-smart irrigation practices

Several climate-smart irrigation strategies are increasingly being adopted to improve irrigation efficiency.

Weather-based irrigation

Irrigation is scheduled according to real-time weather information and crop water requirements.

Soil moisture-based irrigation

Water is applied only when soil moisture falls below the management allowable depletion level, thereby preventing unnecessary irrigation.

Evapotranspiration-based irrigation

Daily crop water loss through evaporation and transpiration is estimated, and irrigation is applied to compensate for these losses.

Deficit irrigation

During less sensitive growth stages, irrigation water is intentionally reduced while ensuring adequate moisture during critical stages such as flowering and grain filling. This approach conserves water without substantially reducing crop yield.

Rainwater harvesting and supplemental irrigation

Farm ponds, check dams, percolation tanks, and rooftop harvesting systems store rainwater for use during dry spells, improving drought resilience.

Drip irrigation

Drip irrigation delivers water directly to the root zone with application efficiencies exceeding 90 per cent. Besides saving 30–70 per cent of irrigation water, it also improves

fertilizer use efficiency and minimizes weed growth.

Variable rate irrigation

Variable Rate Irrigation (VRI) represents one of the most advanced forms of precision irrigation. Using GPS-guided irrigation equipment, wireless controllers, and digital field maps, different areas within a field receive different quantities of water based on soil properties, crop growth, and moisture availability. This site-specific irrigation significantly improves irrigation uniformity and water productivity.

Benefits of precision irrigation

Adoption of precision irrigation offers several agronomic, economic, and environmental advantages.

- Water savings of 20–50 per cent.
- Increased crop yield and improved produce quality.
- Higher fertilizer use efficiency.
- Reduced nutrient leaching and environmental pollution.
- Lower pumping costs and energy consumption.
- Improved groundwater conservation.
- Enhanced resilience to climate variability.
- Reduced greenhouse gas emissions associated with irrigation.
- Better profitability through efficient resource utilization.

Challenges in adoption

Despite its immense potential, large-scale adoption of precision irrigation faces several constraints.

High initial investment

- Requirement for technical expertise.
- Limited internet connectivity in rural areas.



- Maintenance and calibration of sensors.
- Dependence on accurate field data.
- Limited awareness among farmers.

Government support, capacity building, and affordable sensor technologies will be essential for wider adoption.

Future prospects

The future of irrigation lies in intelligent automation. Integration of artificial intelligence, machine learning, drones, satellite remote sensing, cloud computing, and robotics will further improve irrigation decision-making. As climate change intensifies water scarcity, precision irrigation will become an indispensable component of sustainable agriculture, ensuring higher productivity with fewer natural resources.

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Conclusion

Precision irrigation represents a paradigm shift from traditional irrigation practices toward intelligent, resource-efficient water management. By integrating modern sensing technologies, weather forecasting, remote sensing, IoT, and artificial intelligence, precision irrigation enables farmers to maximize water productivity while minimizing environmental impacts. Adoption of this climate-smart technology not only conserves water and energy but also enhances crop yield, profitability, and resilience to climate change. As agriculture moves toward digital transformation, precision irrigation will play a central role in achieving sustainable food production and ensuring long-term water security.

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