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Precision Irrigation: The Key to Water-Efficient Agriculture

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Water is the most critical yet increasingly scarce resource in agriculture. With rising population pressure, climate variability, and declining groundwater reserves, the need to produce “more crop per drop” has become essential. Traditional irrigation practices—often based on fixed schedules or visual assessment—lead to over- or under-irrigation, resulting in water wastage, nutrient leaching, reduced yields, and soil degradation.

Precision irrigation offers a scientific, data-driven solution to this challenge. By applying the right amount of water at the right time and place, it enhances water use efficiency, improves crop productivity and supports sustainable farming systems.

What is Precision Irrigation?

Precision irrigation is an advanced water management approach that uses real-time data, sensors, and decision-support tools to optimize irrigation scheduling and application. It integrates soil, crop, and weather information to ensure that crops receive water exactly when needed and in the required quantity.

Unlike conventional methods, precision irrigation focuses on:

- Spatial variability (different areas of the field)
- Temporal variability (changing crop water needs over time)
- Efficient delivery systems (minimizing losses)

Core Principles of Precision Irrigation

Precision irrigation is built on four fundamental principles—Right Timing, Right Quantity, Right Method, and Right Place. Together, these ensure efficient water use, improved crop productivity, and sustainability. Below is a detailed explanation of each:

1. Right Timing (When to Irrigate)

Right timing means supplying water exactly when the crop needs it—not too early and not too late. This is crucial because both over-irrigation and water stress can reduce crop yield and quality.

In precision irrigation, timing is determined scientifically using:

- Soil moisture monitoring (Tensiometer, FDR, TDR sensors)
- Crop growth stages (critical stages like flowering, tuber formation, grain filling)
- Weather data (temperature, humidity, evapo-transpiration). Right timing prevents crop stress, avoids unnecessary irrigation and improves water productivity. For example, in crops like potato, maintaining optimum soil moisture during tuber initiation is essential. If irrigation is delayed, yield losses occur; if applied too early or frequently, it may lead to diseases and nutrient leaching.

2. Right Quantity (How Much to Irrigate)

This principle focuses on applying the exact amount of water required to bring soil moisture to the optimal level in the root zone. The quantity of irrigation depends on soil type (sandy soils need frequent but smaller doses; clay soils need larger but less frequent irrigation), crop type and growth stage, root depth and evapo-transpiration (ET) rate. Precision irrigation uses calculations or sensor-based data to determine water requirement which avoids over-irrigation (which causes water logging, nutrient leaching, and energy wastage) and under-irrigation (which leads to moisture stress and yield reduction). *e.g.* If soil moisture depletion reaches 40–50% of available water capacity, irrigation is scheduled to refill the root zone up to field capacity. Right time application of irrigation water maximizes water use efficiency, reduces fertilizer loss and saves energy and irrigation cost

3. Right Method (How to Apply Water)

Right method refers to selecting the most efficient irrigation system to deliver water with minimal losses.

Common Precision Irrigation Methods

Drip irrigation is one of the most widely adopted systems due to its high efficiency. In this method, water is applied directly to the root zone of plants through a network of pipes and emitters. By supplying water in small, frequent amounts, drip irrigation maintains optimal soil moisture conditions and significantly reduces evaporation and surface runoff losses. This method is particularly suitable for row crops, vegetables, orchards, and other high-value crops where precise water application is essential for maximizing yield and quality.

Sprinkler irrigation, on the other hand, distributes water in the form of droplets, simulating natural rainfall. Water is sprayed into the air through pressurized nozzles and falls uniformly over the crop canopy and soil surface. This method is well suited for closely spaced crops such as cereals, fodder crops, and lawns, where uniform coverage is required. Modern sprinkler systems can be automated and integrated with sensors and timers, allowing precise control over irrigation scheduling and application rates. Automation enhances efficiency by ensuring that water is applied only when needed, thereby reducing wastage and labor requirements.

Subsurface drip irrigation represents an advanced form of drip irrigation in which water is delivered below the soil surface directly into the root zone through buried emitters. This approach further minimizes evaporation losses and prevents surface water exposure, which can reduce weed growth and disease incidence. Because water is applied beneath the soil surface, it improves water use efficiency and maintains consistent moisture conditions around plant roots. This method is especially beneficial in arid and semi-arid regions where conserving water is critical.

The selection of an appropriate precision irrigation method depends on several factors. Crop type plays a significant role, as different crops have varying water requirements and root structures. Soil characteristics such as texture and infiltration rate, influence how water moves and is retained in the soil. Topography also affects irrigation choice, as uneven or sloping land may require systems that prevent runoff and ensure uniform distribution. Additionally, water availability determines the feasibility of adopting certain irrigation systems, especially in water-scarce regions. Overall, precision irrigation methods offer several key advantages. They ensure uniform distribution of water across the field, reduce losses due to evaporation, runoff, and deep percolation, and enhance overall water use efficiency. Furthermore, these systems are highly compatible with fertigation, enabling the simultaneous application of water and nutrients, which improves nutrient use efficiency and promotes better crop growth and productivity.

4. Right Place (Where to Apply Water)

Right place means delivering water precisely where it is needed—mainly in the active root zone of the crop. In traditional irrigation, water is often applied across the entire field, leading to losses due to evaporation, weed growth in non-crop areas and uneven water distribution of water. Precision irrigation ensures targeted application through: Drip emitters placed near plant roots, zoned irrigation systems and variable rate irrigation (VRI) technologies. For

example, in widely spaced crops, water is applied only near plant rows rather than the entire field surface. It ensures maximum water uptake efficiency, reduced weed growth, minimum nutrient losses and better crop uniformity

Key Technologies in Precision Irrigation

- 1. Soil moisture sensors:** Devices like tensiometers, capacitance (FDR), and TDR sensors measure soil moisture in real time. These sensors help determine when irrigation should be applied.
- 2. Weather-based scheduling:** Weather data (temperature, humidity, wind speed, solar radiation) is used to estimate evapo-transpiration (ET), which indicates crop water requirements.
- 3. Automated irrigation systems:** Automation allows irrigation systems to operate based on sensor readings or pre-set thresholds, reducing labor and human error.
- 4. Remote Sensing and GIS:** Satellite imagery and drones help monitor crop health, soil moisture variability, and irrigation uniformity across large areas.
- 5. Decision Support Systems (DSS):** Software tools integrate multiple data sources and provide irrigation recommendations to farmers.

Benefits of Precision Irrigation

Improved water use efficiency: Water savings of 20–50% compared to traditional methods.

Enhanced crop productivity: Optimal water supply leads to better growth, higher yields, and improved quality.

Reduced input costs: Lower water, energy, and fertilizer usage reduces production costs.

Environmental sustainability: Minimizes groundwater depletion, reduces nutrient leaching and pollution, prevents soil salinity and degradation

Better resource management: Efficient use of labour, water, and energy.

Integration with fertigation: Precision irrigation systems can be effectively combined with fertigation—the application of fertilizers through irrigation water. This ensures: uniform nutrient distribution, reduced fertilizer losses and higher nutrient use efficiency. Split application of nutrients through fertigation aligns nutrient availability with crop demand, leading to improved yield and soil health.

Challenges in Adoption

Despite its advantages, precision irrigation faces several constraints:

- High initial investment (sensors, automation systems)
- Technical knowledge requirement
- Maintenance and calibration issues
- Limited awareness among farmers
- Small land holdings in developing countries

Strategies to Promote Precision Irrigation

- Government subsidies for micro-irrigation systems
- Training and capacity building for farmers
- Development of low-cost sensor technologies
- Mobile-based advisory services
- Integration with watershed and farming system approaches

Future Prospects: The future of precision irrigation lies in smart farming technologies such as:

- Internet of Things (IoT)-based irrigation systems
- Artificial Intelligence (AI) for predictive irrigation scheduling
- Cloud-based farm management platforms
- Integration with climate-smart agriculture practices

These innovations will make irrigation more efficient, accessible, and scalable for farmers worldwide.

Conclusion

Precision irrigation represents a transformative approach to water management in agriculture. By combining scientific knowledge with modern technology, it enables farmers to optimize water use, increase productivity, and ensure environmental sustainability. In a world facing increasing water scarcity and climate uncertainty, adopting precision irrigation is not just an option—it is a necessity for achieving sustainable and resilient agricultural systems.

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