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Water-Smart Agriculture and Climate-Resilient Crop Production

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Agriculture is facing increasing pressure from water scarcity, erratic rainfall, rising temperatures, droughts, floods and other climate-related stresses. Water-smart agriculture offers an important approach for improving crop productivity while conserving limited water resources. It promotes efficient irrigation, soil moisture conservation, rainwater harvesting, precision water management, suitable crop varieties and improved agronomic practices. Climate-resilient crop production further strengthens agricultural systems by helping crops withstand drought, heat, irregular rainfall and other climatic stresses. Technologies such as drip irrigation, soil-moisture sensors, remote sensing, automated irrigation, drones and digital advisory systems are creating new opportunities for efficient water management. Water-smart agriculture can improve water productivity, reduce production risks and contribute to sustainable food security. Therefore, integrating efficient water management with climate-resilient crop production is essential for building sustainable and productive agriculture for the future.

Keywords: Climate resilience, irrigation management, precision agriculture, water productivity, water-smart agriculture, sustainable agriculture

Introduction

Water is one of the most important resources for agricultural production. Agriculture remains the largest user of freshwater globally, while climate change is making water availability increasingly uncertain. FAO notes that agriculture accounts for about 72% of global freshwater withdrawals and that climate change is increasing pressure on agricultural water resources. Farmers are increasingly experiencing irregular rainfall, prolonged dry periods, heat waves, floods and changes in crop growing seasons. These conditions can affect seed germination, crop establishment, vegetative growth, flowering, seed formation and final yield. In this situation, agriculture needs a shift from conventional water use towards water-smart agriculture, where water is applied according to crop requirement, soil condition and climatic conditions. Climate-smart agriculture integrates adaptation and mitigation with sustainable agricultural development and recognizes that water management is central to climate resilience.

What is Water-Smart Agriculture

Water-smart agriculture is an approach that aims to produce more food with better management of available water resources. It does not simply mean reducing irrigation. Instead, it means using the right amount of water, at the right time and in the right place. Important components of water-smart agriculture include:

- Efficient irrigation methods
- Proper irrigation scheduling
- Soil-moisture monitoring

- Rainwater harvesting
- Mulching and moisture conservation
- Drip and sprinkler irrigation
- Precision irrigation
- Improved soil health
- Drought-tolerant crop varieties
- Recycling and efficient use of available water

Climate-Resilient Crop Production

Climate resilience refers to the ability of agricultural systems to maintain productivity and recover from climatic stresses. Climate-resilient crop production combines suitable varieties with improved agronomic and water-management practices.

Major climate stresses affecting crop production include:

- Drought
- Heat stress
- Erratic rainfall
- Flooding
- Waterlogging
- Salinity
- Changes in growing seasons
- Extreme weather events

Crop varieties with drought, heat or salinity tolerance can help reduce production losses under stressful conditions. Crop diversification and suitable cropping systems can further reduce dependence on a single crop.

Smart Irrigation Technologies

Efficient irrigation is one of the major components of water-smart agriculture. Conventional irrigation can result in unnecessary water application, runoff and deep percolation when irrigation is not matched with crop demand.

Modern technologies can improve irrigation management through:

1. **Drip irrigation** – supplies water close to the crop root zone.
2. **Sprinkler irrigation** – distributes water in the form of droplets.
3. **Soil-moisture sensors** – help determine soil water availability.
4. **Tensiometers** – Indicate soil water tension and help in irrigation scheduling.
5. **Automated irrigation** – Can operate irrigation according to sensor-based information.
6. **Remote sensing** – Helps identify crop water stress over larger areas.
7. **Variable-rate irrigation** – Allows irrigation to be adjusted according to field variability

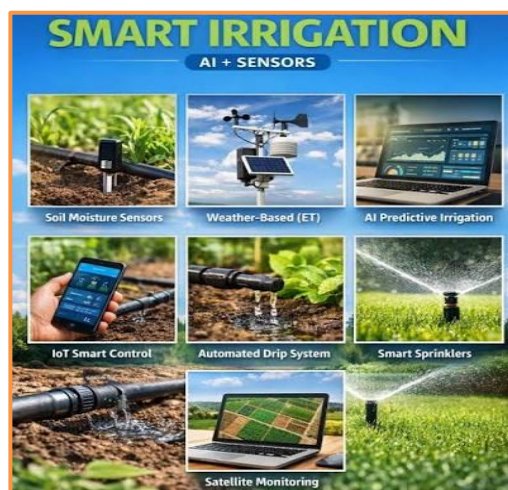
Major Water-Smart Technologies and Their Applications

Technology	Major application	Main benefit
Drip irrigation	Root-zone water application	Reduces water losses
Sprinkler irrigation	Uniform field irrigation	Efficient water distribution
Soil-moisture sensor	Monitoring soil moisture	Irrigation based on crop need
Tensiometer	Measuring soil water tension	Better irrigation scheduling
Remote sensing	Crop and water-stress monitoring	Large-area assessment
Drones	Crop monitoring	Early detection of crop stress
Automated irrigation	Automatic water application	Saves labour and improves timing
Weather-based irrigation	Irrigation scheduling	Responds to weather conditions
Variable-rate irrigation	Field-specific water application	Addresses spatial variability

Soil Moisture Conservation

Soil is an important natural reservoir of water. Improving soil health can increase water storage and availability to crops. Important soil moisture conservation practices include:

- Mulching
- Crop residue retention
- Conservation tillage
- Cover crops
- Organic manure application
- Crop rotation
- Contour farming
- Proper land levelling



Rainwater Harvesting and Farm Water Security

Rainwater harvesting is particularly important in rainfed and water-stressed agricultural regions. Rainfall can be collected and stored for later use through farm ponds, check dams, contour structures and other water-harvesting systems. FAO identifies rainwater harvesting and small-scale water storage as important approaches for improving the reliability of water supply, especially where rainfall is variable.

The basic principle is:

Capture water when it is available and use it efficiently when it is needed.

Role of Crop Selection

Selecting suitable crops and varieties is an important component of climate-resilient agriculture. Crops with shorter duration, drought tolerance, heat tolerance or other stress-adaptive characteristics can reduce climate-related production risks. Farmers can also adopt crop diversification by including cereals, pulses, oilseeds, millets and horticultural crops according to local climate, soil and market conditions.

Role of Digital Agriculture

Digital technologies are becoming increasingly important in water-smart agriculture. Sensors, GPS, GIS, remote sensing, drones, Internet of Things (IoT) and artificial intelligence can provide information for better farm decisions. Satellite-based systems can monitor crop water use and productivity. FAO's WaPOR platform, for example, uses remote-sensing information to support improved water productivity and irrigation management. Digital agriculture can help farmers and agricultural professionals answer important questions such as:

- When should irrigation be given?
- How much water is required?
- Which part of the field is under water stress?
- Which crops are responding well?
- Where are water losses occurring?

Water Productivity: More Crop per Drop

Water productivity refers to the amount of agricultural output obtained per unit of water used. Improving water productivity does not necessarily mean reducing yield. The objective is to obtain higher or stable crop production with efficient use of available water.

Water productivity can be improved through:

- Timely irrigation
- Efficient irrigation systems
- Improved crop varieties
- Proper nutrient management
- Weed management
- Soil moisture conservation

- Precision farming
- Reduction of water losses

Climate-Smart Practices for Crop Production

Climate-resilient crop production can be strengthened through an integrated approach.

1. Efficient Water Management

Apply irrigation according to crop requirement and soil moisture.

2. Conservation Agriculture

Reduce unnecessary soil disturbance and conserve crop residues.

3. Improved Soil Health

Increase organic matter and biological activity in the soil.

4. Stress-Tolerant Varieties

Use suitable varieties for drought, heat, salinity or other local stresses.

5. Crop Diversification

Reduce production risk by adopting suitable crop combinations.

6. Weather-Based Decisions

Use weather forecasts and advisories for irrigation, sowing and crop protection.

7. Precision Agriculture

Use sensors, remote sensing and digital technologies for site-specific crop management.

Benefits of Water-Smart Agriculture

Water-smart agriculture provides several benefits:

- Improves water-use efficiency
- Conserves groundwater and surface water
- Reduces unnecessary irrigation
- Improves crop water productivity
- Supports stable crop production
- Reduces climate-related production risks
- Improves soil moisture conservation
- Reduces production costs in suitable situations
- Supports sustainable use of natural resources
- Strengthens food and livelihood security

Challenges

Despite its potential, several challenges can limit adoption of water-smart agriculture:

- High initial cost of some technologies
- Limited technical knowledge
- Small and fragmented landholdings
- Poor access to reliable irrigation infrastructure
- Limited availability of quality equipment and services
- Lack of awareness about irrigation scheduling
- Maintenance requirements of modern irrigation systems
- Limited access to real-time weather and soil information

Therefore, farmer training, extension services, affordable technologies, research and supportive policies are important for wider adoption.

Future Prospects

The future of water-smart agriculture will increasingly involve integration of agronomy, irrigation science, sensors, remote sensing, artificial intelligence and climate information. Smart irrigation systems can combine soil moisture, weather and crop information to support irrigation decisions. Remote sensing can monitor crop water stress, while automated systems can improve the timing and precision of irrigation. ICAR has also highlighted the increasing role of machine learning, GPS, GIS, drones, automation and IoT-enabled precision irrigation in strengthening water-smart agriculture.

The development of climate adaptation tools is also expanding. In 2025, ICAR and regional partners launched the Atlas of Climate Adaptation in South Asian Agriculture to support understanding and planning for climate-related risks such as droughts, heatwaves, floods and erratic rainfall.

Conclusion

Water-smart agriculture is an important pathway for sustainable crop production under increasing water scarcity and climate variability. Efficient irrigation, soil moisture conservation, rainwater harvesting, improved crop varieties and digital technologies can help farmers use water more effectively. Climate-resilient crop production requires an integrated approach in which water, soil, crop, climate and technology are managed together. Water-smart agriculture can therefore contribute to improved water productivity, stable crop yields, resource conservation and long-term food security.

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