SUNSHINE AGRICULTURE e-Newsletter

ISSN (E): 2583 – 0821

Sun. Agri.:e- Newsletter, (2025) *5*(10), 29-31

Article ID: 457

Utilization of Hydrogel and Moisture Conservation Techniques to Improve Water Use Efficiency

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Available online at

www.sunshineagriculture.vitalbiotech.org

Article History

Received: 27. 9.2025

Revised: 2. 10.2025

Accepted: 7. 10.2025

INTRODUCTION

Agriculture accounts for nearly 70% of global freshwater consumption. Conventional irrigation methods often result in inefficient water use, leading to resource depletion, soil degradation, and environmental concerns. Enhancing WUE in agriculture is therefore critical, particularly under the challenges posed by climate change and increasing water scarcity.

Hydrogels, or superabsorbent polymers, have emerged as innovative solutions to mitigate water stress in crops. These polymers can absorb water many times their dry weight and gradually release it to the soil, maintaining optimum moisture levels during dry periods. Combining hydrogels with traditional moisture conservation techniques, including mulching, reduced tillage, and rainwater harvesting, creates an integrated approach that improves both water retention and crop productivity. This integrated methodology aligns with sustainable agriculture goals by promoting resource efficiency and resilience against drought conditions.

2. Hydrogels in Agriculture

2.1 Definition and Classification

Hydrogels are three-dimensional, cross-linked polymer networks capable of absorbing and retaining significant amounts of water relative to their mass. They can be classified into:

Synthetic Hydrogels: Made from petroleum-based polymers such as polyacrylamide and polyacrylate. These hydrogels have high water retention capacities but may have limited biodegradability.

Natural Hydrogels: Derived from natural materials like starch, cellulose, chitosan, or mango seed kernels. They are environmentally friendly and biodegradable, offering sustainable alternatives for agricultural use.

Source: https://www.sciencedirect.com/science/article

ISSN (E): 2583 – 0821

2.2 Mechanism of Action

Hydrogels operate through absorption and gradual release of water:

1. **Absorption:** Hydrogels absorb water during irrigation or rainfall, swelling to retain water.
2. **Release:** During dry periods, they release stored water slowly, maintaining soil moisture for plant roots.

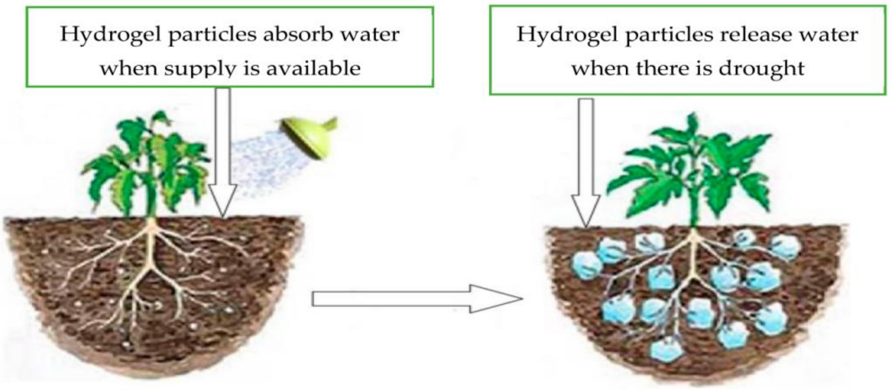
Additional benefits include improving soil structure, reducing compaction, and enhancing nutrient retention. Hydrogels create a microenvironment around roots that reduces water stress and supports healthier crop development.

2.3 Application Methods

Hydrogels can be applied in several ways:

- Mixed with soil during planting
- Placed in planting holes or furrows
- Integrated with fertigation systems

Application rates vary depending on crop type, soil texture, and hydrogel type. For sandy soils, hydrogels are particularly effective due to their low natural water-holding capacity.



Source: https://www.mdpi.com

3. Moisture Conservation Techniques

3.1 Mulching

Mulching involves covering the soil surface with organic (straw, leaves, husk) or inorganic (plastic sheets) materials. Benefits include:

- Reducing soil evaporation
- Maintaining soil temperature
- Suppressing weed growth

When combined with hydrogels, mulching further reduces water loss and enhances crop growth under drought conditions.

3.2 Reduced Tillage

Reduced or conservation tillage minimizes soil disturbance, preserving soil structure and organic matter. Advantages include:

- Better water infiltration
- Lower evaporation rates
- Enhanced root penetration

Hydrogels integrated into reduced tillage systems retain water efficiently in the topsoil, enhancing crop productivity.

3.3 Rainwater Harvesting

Rainwater harvesting involves collecting and storing runoff water for irrigation. When coupled with hydrogels, stored water infiltrates efficiently into the soil, reducing dependency on groundwater or supplemental irrigation.

3.4 Other Techniques

- Contour bunding and terracing to reduce runoff
- Drip irrigation combined with hydrogel application for precise water delivery
- Cover cropping to reduce evaporation and improve organic matter content

4. Integration of Hydrogels and Moisture Conservation

Combining hydrogels with traditional moisture conservation methods provides synergistic benefits:

1. **Enhanced Soil Moisture Retention:** Hydrogels absorb and slowly release water, while mulching and reduced tillage minimize loss.
2. **Increased Crop Yields:** Improved moisture availability reduces crop stress, promoting higher productivity.
3. **Resource Efficiency:** Water, fertilizer, and labor are used more efficiently.
4. **Sustainability:** Natural hydrogels and organic mulches reduce environmental impact and support long-term soil health.

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5. Case Studies and Applications

5.1 Corn Cultivation in Semi-Arid Regions

- Hydrogel application improved soil water content and increased maize yield by 15–20% compared to control plots.
- Reduced irrigation frequency led to water savings of up to 25%.

5.2 Onion Farming in Morocco

- Hydrogels applied with mulching enhanced soil moisture retention and crop productivity.
- Irrigation requirements reduced by 30%, demonstrating economic and environmental benefits.

5.3 Mango Seed Hydrogel Innovation

- Bihar Agricultural University developed a biodegradable hydrogel from mango seed kernels.
- Water absorption capacity increased fourfold, offering a cost-effective, eco-friendly solution for water-limited regions.

6. Challenges and Limitations

Cost: High-quality hydrogels may be expensive for smallholder farmers.

Soil Compatibility: Sandy soils benefit more than clayey soils, requiring site-specific application.

Environmental Impact: Long-term effects of synthetic hydrogels on soil microorganisms need further research.

Scalability: Large-scale adoption requires farmer training and infrastructure development.

7. Future Prospects

- Development of biodegradable hydrogels from agricultural waste materials.
- Integration with precision irrigation technologies to optimize WUE.
- Policy support and farmer awareness programs to promote adoption.
- Further research on hydrogel-soil-microbe interactions to enhance soil fertility.

CONCLUSION

Hydrogels, combined with moisture conservation techniques, present a viable strategy to improve water use efficiency in agriculture. They mitigate water stress, reduce irrigation requirements, and enhance crop productivity. Sustainable adoption of these practices, supported by research, policy, and farmer training, can significantly contribute to agricultural sustainability and water resource management in arid and semi-arid regions.

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