

Role of hydrogel in dryland agriculture

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Introduction

In the arid and semiarid climates of the world, water scarcity is a major environmental problem due to the low amount of rainfall with irregular spatial and temporal distribution which seriously hampers the sustainability of agriculture. In limited water supply conditions, the modern approach of water-saving deficit irrigation technologies is considered a critical component to ensure favourable soil moisture balance in the root zone with increased water use efficiency without hampering crop yield and its quality. Presently, the advancement of modern micro irrigation technologies such as low-pressure micro sprinkler and drip irrigation systems with optimum irrigation scheduling coupled with plastic mulching can solve the problems by reducing drastically the consumption of irrigation water and improved water use efficiency. However, these high-techs are explicitly employed in high-value crops and require sufficiently large capital investment, recurring operational expenditure and expertise skills of the farmers.

Recently, hydrogel polymer technology has been widely used in the agricultural sector as soil conditioner because of its multifunctional roles in excellent water absorbency and water-retaining ability. The polymers maintain a very high water swelling and releasing capacity of moisture under water deficit conditions and consequently enhance water and nutrient use efficiency by checking evaporation loss, deep water percolation, and nutrient leaching under the arid and semiarid climates of the world by improving plant development and crop yield.

Different methods for conserving water and reducing water use in agriculture

Ex-situ methods

- Bench terrace
- Contour bunding
- Creek bunding
- Micro irrigation systems (viz. drip and sprinkler irrigation)

In-situ methods

- Tillage practices (zero tillage, conservation tillage, minimum tillage, etc.)
- Cultural practices (opening of furrows between rows of crop and sowing on ridges; furrow method, compartmental bunding, mulching, etc.)

- Use of chemicals (antitranspirants and hydrogel).

Hydrogel

Hydrogel, popularly known as “root watering crystal,” “water retention granules,” or “raindrop,” is a quasi-solid phase amorphous material. Hydrogels are cross-linked polymers with a hydrophilic group which have the capacity to absorb large quantities of water without dissolving in water. Water absorption capacity arises from the hydrophilic functional groups attached to the polymer backbone while their resistance to dissolution arises from cross-links between network chains. Cross-linked variants of poly acrylamide have shown greater resistance to degradation; hence, they are more stable for longer periods (2–5 years). Acrylamide is toxic (neurotoxic), but polyacrylamide is non-toxic. It is highly water-absorbent and forms a soft gel when hydrated.

Common hydrogel agriculture's ingredient is potassium polyacrylate or sodium polyacrylate. As a superabsorbent material, it can absorb plenty of water and turn water to gel to store water.

Hydrogel agriculture technology uses insoluble gel-forming polymers to improve the water-holding properties of different soils, such as clays and sandy loams. This can increase water-holding and water use (up to 85% for sand), improve soil permeability, reduce the need for irrigation, reduce compaction, soil erosion, and leaching, and improve plant growth. Desertification and lack of water threaten agriculture in many arid and semi-arid regions of the world; these may be mitigated with hydrogels.

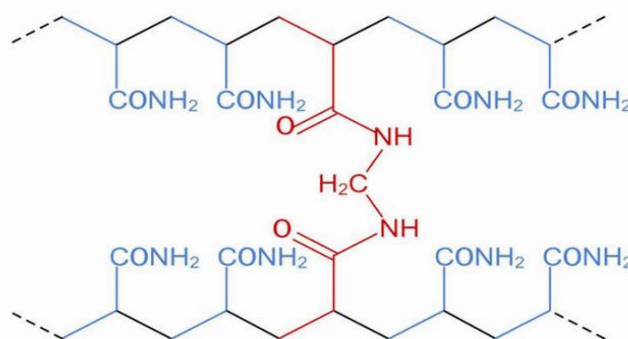


Fig 1. Structure of hydrogel

Water absorption mechanism of hydrogel

The hydrophilic groups (viz. acrylamide, acrylic acid, acrylate, carboxylic acid, etc.) of the polymer chain are responsible for water absorption in hydrogels. The acid groups are attached to the main chain of the polymer. When

these polymers are put in water, the latter enters into the hydrogel system by osmosis and hydrogen atoms react and come out as positive ions. This leaves negative ions along the length of the polymer chain. Hence the hydrogel now has several negative charges down its length. These negative charges repel each other. This forces the polymer chain to unwind and open up. They also attract water molecules and bind them with hydrogen bonding.

Hydrogel can absorb more than 400 times its weight of water by this mode. When its surroundings begin to dry out, the hydrogel gradually dispenses up to 95% of its stored water. When exposed to water again, it will rehydrate and repeat the process of storing water. This process can last up to 2–5 years, by which time biodegradable hydrogel decomposes.

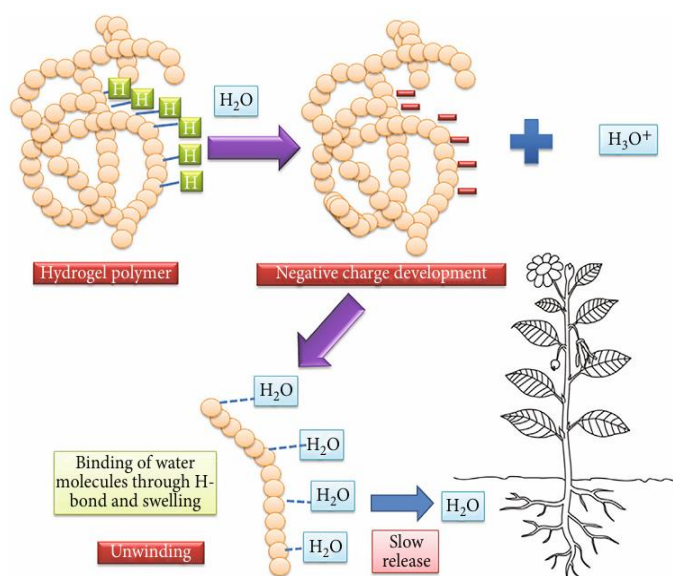


Fig 2. Mechanism of action of hydrogel upon soil-based application

Absorption capacity of hydrogels

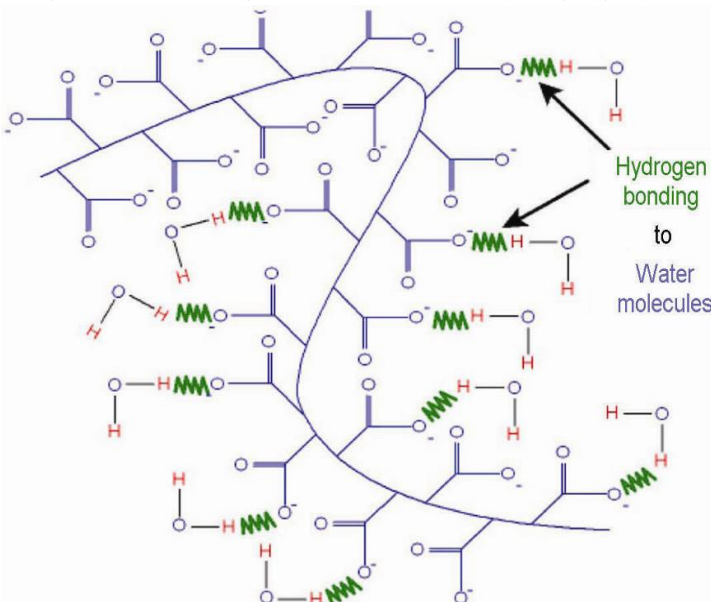
Water contains Ca^{++} and Mg^{++} ions. When hydrogel absorbs water, these ions react with negative sites in the polymeric chain resulting in the formation of non-soluble salts which block the negative ion sites. This blockage increases with the salinity of water and further cycles of wetting and drying. The water absorption capacity of hydrogels decreases due to these two factors.

Functional characteristics of a hydrogel: The features of the ideal hydrogel materials should include the following:

- The high-water absorption capability
- The desired rate of absorption and desorption capacity according to plant requirement
- Lowest soluble content and residual monomer
- High durability and stability during swelling and storage
- High biodegradability and biocompatibility

- High performance over a wide temperature range
- After swelling, water becomes neutral in pH
- Colourlessness, odorlessness, and nontoxic
- Upscale the soil's physical, chemical, and biological properties
- Photostability, rewetting capability for a longer time, low-cost material, and eco-friendly.

Fig 3. Water absorption mechanism of hydrogel polymer



Water retention and release behaviour work in a hydrogel

- The hydrophilic groups, viz., acrylamide, acrylic acid, acrylate, carboxylic acid, etc., of the polymer chain are responsible for water absorption in a hydrogel
- When the polymers come in contact with water, the water penetrates the hydrogel system by osmosis, and hydrogen atoms react and come out as positive ions
- This process leaves several negative ions along the length of the polymer chain. These negative charges repel each other and force the polymer chain to unwind and open up and attract water molecules and bind them with hydrogen bonding
- The hydrogel can absorb more than 400-1500 times their dry weight of water in this process and act as a miniature water reservoir. When the surrounding around the root zone begins to dry up, the hydrogel gradually dispenses up to 95% of its stored water to plant absorption
- Under exposition to rewetting condition, rehydration starts and the process of storing water continues
- This polymer has the ability to increase water retention in soil which facilitates higher water uptake and water use efficiency, thus helping in

reducing the water stress of plants and increasing crop growth and yield

- These undergo volume transition in response to physical and chemical stimuli depending on the prevailing environmental conditions
- The hydrogels are biodegradable and decompose in the soil after working for 2-5 years and thus do not alter the physicochemical properties of the soil

Classification of hydrogel

Based on the source, hydrogel for agricultural use is classified into three types:

- (i) Natural hydrogel
- (ii) Semiartificial hydrogel
- (iii) Artificial hydrogel

The petroleum based synthetic or artificial hydrogels available in the market are categorized mainly into three types based on their chemical composition and configuration as follows:

- (i) Starch-polyacrylonitrile graft polymers (starch copolymers)
- (ii) Vinyl alcohol-acrylic acid copolymers (polyvinyl alcohols)
- (iii) Acrylamide sodium acrylate copolymers (cross linked polyacrylamides)

Use of hydrogel in agriculture

- Hydrogels are used to improve the ability of soil to absorb water. They are prepared by grafting and cross linking of water-absorbent polymers (polyacrylamide) onto a cellulose derivative backbone polymer chain (carboxymethyl cellulose). These hydrogels are more biodegradable and therefore safer to the environment.
- Unlike super absorbent polymers employed in hygienic applications which must possess the fast rate of fluid absorption and ability to retain it under high load, the agricultural hydrogels should not only have the ability to absorb water, but must release the same gradually according to specific requirements of the plants

Novel characteristics of hydrogel for agricultural use:

The hydrogels as soil conditions have the following characteristics

- (i) Resistant to salt concentrations in soil
- (ii) Improve the physical, chemical, and biological properties of soil
- (iii) Promote seed germination, seedling growth, root growth, plant density, and yield

- (iv) Higher water absorption in water excess and gradual release under drought stress
- (v) Alleviate the plants from moisture stress and can tolerate prolonged moisture stress
- (vi) Delay onset of the permanent wilting point under intense evaporation in the arid environment
- (vii) Render more efficient water consumption
- (viii) Enhance water use efficiency by minimizing evaporation and leaching loss of water
- (ix) Reduce irrigation frequencies, fertilizer requirement of crop, and irrigation cost
- (x) Maximum stability and durability in soil
- (xi) No environmental hazards
- (xii) High performance at high temperatures (40-50°C), hence suitable for hot and dry climates

Methods of hydrogel application in agriculture:

Hydrogels as soil conditioners are used for stabilizing surface soils to inhibit crust formation, to improve poor structure soil at greater depths by aggregation, to increase water-holding capacity, and to enhance plant growth and development. The rate of application of hydrogel in agriculture depends upon the soil texture. In clay soil, it is 2.5 kg ha⁻¹ at 6-8" soil depth, and for sandy soil, it is up to 5.0 kg ha⁻¹ at 4" soil depth. There are mainly two methods for applying hydrogels in soils:

(i) **Dry method to subsoil:** a dry polymer such as polyallylamine (PAAm) or polyvinyl alcohol (PVA) is applied to the subsoil by mixing with sandy soil to 15-25cm depth, moistening the soil for swelling before cultivation. After the polymer has swollen, the soil structure is improved and water penetration and retention capacity are increased.

(ii) **Wet method to topsoil:** the polymer solution is sprayed onto initially wetted topsoil, followed by drying for water-stable aggregate stability and immediate sowing. This wet method can reduce water consumption, decrease soil erosion, and increase soil hydraulic conductivity. In the spray technique, the hydrogel can also be mixed with micronutrients and pesticides.

Impact of hydrogel polymer on soil properties

The application of the hydrogel as soil conditioners or amendments can improve the soil properties of the arid and semiarid regions in the following ways:

- (i) Improve the structure of coarse-textured soil by altering the physical (viz., porosity, bulk density, water-holding capacity, soil permeability, percolation and infiltration rate, soil temperature, etc.), chemical (CEC, etc.), and biological environments through aggregation, solidification
- (ii) Prevent crust formation stabilization

- (iii) Accomplish favourable growth medium by reducing soil bulk density, providing better ventilation and moisture regime for supporting plant viability, growth, and yield
- (iv) Increase soil water retention capacity, higher water supply to plant roots, and efficient water uptake; reduce the frequency of irrigation because of the decline of water losses by leaching and evaporation and protect the plants against soil water stress
- (v) Inhibit soil losses by water and wind erosion and runoff
- (vi) Control seepage by the formation of membranes in soil that regulate the movement of water and nutrient downwards, increase soil permeability and infiltration, improve aeration and soil drainage, and prevent salt toxicity injury to plants
- (vii) Increase water and nutrient use efficiencies and water saving to plants
- (viii) Play havoc roles in light as well as heavy soils, where water scarcity prevailed

Hydrogels are environment friendly:

Biodegradable hydrogels contain labile bonds either in the polymer backbone or in the cross-links used to prepare the hydrogels. The labile bonds can be broken under physiological conditions either enzymatically or chemically over a period of time. End-products after degradation are CO₂, water and ammonia.

Acrylamide, a monomer used for hydrogel preparation is neurotoxic, but polyacrylamide itself is **non-toxic**. The polyacrylamide can never reform its monomer. Hence there is no residual amount of acrylamide present in the soil after degradation of hydrogel, especially when cellulose is used as backbone. Acrylamide residue is also not detected in crop products which are grown with hydrogel application.

Benefits of hydrogel in agriculture

(i) Hydrogels act as “**miniature water reservoirs**” near the root zone of plants. It can absorb both natural and supplied water 400-1500 times of its own weight and release it slowly on water shortage conditions by root capillary suction mechanism

(ii) It can perform the cyclic process of absorption and desorption of water, can supply optimum plant available moisture for quick seed germination and seedling establishment, and can increase the growth and high yield of the crop

(iii) In cold regions, the use of hydrogels does not freeze the moisture absorbed in the structure and makes easy

accessibility to the plants, thereby regulating seedling growth temperature and preventing death by freezing

(iv) It can decrease soil osmotic moisture; save irrigation water, labour, and production cost; reduce irrigation requirement of crops; mitigate drought conditions; prevent leaching and runoff of water and nutrients; improve water and nutrient use efficiencies in plants; and restore soil microorganisms and enzymes

(v) It can help the plant to withstand the prolonged moisture stress by delaying the onset of permanent wilting of the plant

(vi) It can reduce the overuse of minerals including micronutrient fertilizers and pesticides

(vii) It can prevent soil compaction, improve soil aeration, and release soil mineral nutrients

(viii) It can enhance stronger and healthier plant growth and marketable yield

Recommendation of hydrogel

For field crops: Prepare an admixture of hydrogel and fine dry soil in 1: 10 ratio and apply along with the seeds/fertilizers or in the opened furrows before sowing. For best results, hydrogel should be close to seeds.

In nursery bed for transplants: Apply 2 g/m² (or according to recommended rate) of nursery bed mix of hydrogel uniformly in the top 2 inches of the nursery bed. In pot culture, mix 3-5 g/kg of soil before planting.

While transplanting: Thoroughly mix 2 g (or according to recommended rate) of hydrogel per litre of water to prepare a free-flowing solution; allow it to settle for half an hour. Dip the roots of the plant in the solution and then transplant in the field.

Commercialization

In 2015, The Indian Agriculture Research Institute (IARI) reported the development of a novel hydrogel for agricultural use. It was intended to help farmers to cope with drought, making efficient use of water in arid and semi-arid regions of India. The product is to be commercialized by the Ministry of Science and Technology's National Research Development Corporation (NRDC) in collaboration with a company based in Chennai, Reliance Industries Limited.

In 2016, a water absorbing material named **Alsta hydrogel** was introduced in the India agriculture market after testing from NTC Pune with a potential to absorb water 400 times of its own weight. It is a potassium polyacrylate based granular non-toxic polymer and soil conditioner that is compatible with all kind of soils and crops to greatly reduce irrigation frequency and loss of soil moisture by leaching and evaporation.

Alsta hydrogel, as many others, does not present any internationally recognised certificate about its non-toxicity on human, animal or microorganisms naturally present in soils, neither on its biodegradability or its transfer of elements to the plants growing with it. Statements remain to be measured by an independent certified laboratory.

Conclusion

Water is becoming the most limiting factor for sustainable crop production in arid and semiarid regions. Hydrogel application increases productivity in almost all the test crops (cereals, vegetables, oilseeds, flowers, spices, etc.) in terms of crop yield. It also helps improve the quality of agricultural produce in terms of plant biomass, fruit and flower size and colour with improvement in hydro-physical and biological environment of the soil.

Hence hydrogels may become a practically convenient and economically feasible option in water-stressed areas for increasing agricultural productivity with environmental sustainability. This envisages that the beneficial application of hydrogel on a large scale could be a boon to the farmers and other stakeholders for the optimization of water resource management for higher yield in agriculture.

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