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Hydrogel: A Boon for Agriculture

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SUMMARY

A hydrogel is a 3-D network of hydrophilic polymers that can absorb and retain a significant amount of water or other aqueous solutions. Agricultural hydrogels are commonly known as water-absorbing granules, as they expand significantly when exposed to water. Due to the prevalence of arid and semiarid regions in India, there is a critical need for a more effective utilization of water in agriculture. Super Absorbent Polymers (SAPs) hydrogels have the ability to significantly expand and absorb a substantial volume of water or aqueous solutions. This characteristic has resulted in numerous real-world uses for these innovative materials, especially in the agricultural sector, where they are employed to enhance soil moisture retention and provide plants with a more reliable water source. The efficiency of the hydrogels varies based on their chemical attributes and molecular weight, and these properties can have distinct impacts on different soil characteristics.

INTRODUCTION

Agriculture faces non-living environmental pressures such as drought, salinity, and temperature fluctuations, and these challenges are expected to grow due to factors like land degradation, urban expansion, and climate change. In India, a significant portion of the land falls within arid and semi-arid regions. The availability of irrigation water is diminishing, and globally, there is a growing need for water-efficient agricultural practices. The growing need for food and the diminishing water resources pose challenges to food security (Kreye et al., 2009). In these regions, it is essential to implement effective management practices to preserve soil moisture and enhance water retention capacity. Consequently, crop yields may be lower compared to more favorable conditions. The most effective solution to address this issue is the use of hydrogels. Hydrophilic gels known as "hydrogels" are networked substances capable of absorbing significant volumes of water or aqueous solutions without dissolving. Their distinctive features include their softness, smartness, and their ability to retain water, making them unique in nature (Shibayama and Tanaka, 1993). Naturally occurring polymers that can form hydrogels encompass proteins like collagen and gelatin, as well as polysaccharides such as alginate and agarose.

Conventionally, synthetic polymers that create hydrogels are typically produced through chemical polymerization techniques. Essentially, a hydrogel is comprised of a single polymer molecule, where the network chains within the gel are linked together to constitute a single large molecule when examined on a macroscopic scale. The gel state represents a condition that falls between being entirely liquid and fully solid. These characteristics of being part liquid and part solid give rise to intriguing relaxation behaviors that are distinct from those observed in either a pure solid or a pure liquid state. Hydrogels can display significant alterations in volume in response to various external factors, including temperature, solvent quality, pH, electric fields, and more (Tanaka, 1978). Agricultural hydrogels are typically artificial polymers derived from petroleum-based materials. Consequently, they are referred to as Super Absorbent Polymers (SAPs). The key components that underpin these applications are their ability to absorb and retain water.

Characteristics of Super Absorbent Polymers (SAPs)

Considering the water-absorbing properties of SAP materials, there has been a growing interest in exploring their potential applications in agriculture as a means to address specific agricultural challenges. SAP hydrogels have the potential to impact soil characteristics such as permeability, density, structure, texture, evaporation, and the rate at which water infiltrates the soil. In dry regions, the use of SAP in sandy soil to augment its water-holding capacity appears to be a particularly effective method for enhancing plant quality. These SAP particles can be likened to "small-scale water reservoirs" within the soil. They release water in response to root demand driven by osmotic pressure differences. Furthermore, hydrogels function as a controlled release system, facilitating the absorption of certain nutrient elements, holding them securely, and retarding their dissolution. As a result, plants can continue to access some of the fertilizers, leading to improved growth and performance. SAPs have versatile applications as retention materials, including their use as seed additives to support germination and seedling establishment, seed coatings, root immersion solutions, and as a means to immobilize plant growth regulators or protective agents for controlled and gradual release.Due to changes in crop systems, irregular rains, deepening of water levels and high salt edification, our state has a decline in the facility of drinking water. In addition, if the rains are late, the chances of crop failure also increase. Therefore, hydrogels developed by the Indian Agricultural Research Institute, New Delhi, can play an important role in tackling the problem of low drinking water and rainfall in such a situation. which is the Ministry of Agriculture, Science and Technology, Government of India, as well as I.C.A.R. made available to farmers by.

The salient features of hydrogel are given below,

- Reduced impact from salt content
- It can absorb water up to 400 times its dry weight and then releases it gradually.
- Demonstrates its maximum water-absorbing capability at temperatures ranging from 40°C to 50°C, which are typical of semi-arid and arid soils.
- Remains stable in the soil for at least one year. Requires low application rates in soil, such as 1-2 kg per hectare for nursery horticultural crops and 2.5-5 kg per hectare for field crops.
- Mitigates the leaching of herbicides and fertilizers.
- Delays the occurrence of the permanent wilting point for plants.
- Enhances the rate of seed germination and the emergence of seedlings.
- Enhances a plant's ability to endure prolonged periods of moisture stress.
- Boosts root development and increases root density leading to improved efficiency in water and nutrient utilization.
- Improves the physical properties of soils and soilless growing media.
- Reduce the time needed for nursery establishment.
- Decreases the need for irrigation and fertigation in crop cultivation.

Hydrogel for agriculture

- Excellent water absorption ability in saline and hard water conditions.
- less soluble content and residual monomer.
- Demonstrates high durability and stability during swelling and storage.
- Achieves optimal Absorbency Under Load (AUL).
- (AUL: It is a measure of the water-absorbing capacity of a material, such as a hydrogel or a superabsorbent polymer, when subjected to a mechanical load or pressure)
- Maintains pH neutrality after swelling in water.
- Exhibits photo stability.
- Maintains rehydration capability.
- Gradual biodegradability without the creation of harmful substances.

Physical and chemical properties of hydrogels

The primary characteristics of hydrogels when applied as soil moisture-absorbing materials are closely related to their swelling behavior, which is contingent on both the hydrogel's structure and the surrounding environmental conditions. Because hydrogels are typically composed of polyelectrolytes, their structural features can be described through thermodynamic interaction parameters, mesh point density, the proportion of ionic groups, and the extent of their dissociation. The extent of hydrogel swelling at equilibrium is determined by the absence of swelling pressure within the hydrogel. This pressure results from a combination of osmotic forces, the elasticity of the gel structure, and the presence of relevant ions. The swelling process is empirically examined using techniques involving optical measurements of the gel's physical dimensions, the observation of properly shaped samples, and the automated recording of the remaining volume of liquid after it's absorbed by the sample.

Types of hydrogel

Hydrogels, often referred to as cross-linked three-dimensional networks of water-absorbent polymers, come in three primary categories that have proven suitable for agricultural applications.

1. Starch-graft copolymers
2. Cross-linked Polyacrylates
3. Cross-linked Polyacrylamides and Acrylamide-acrylate copolymers

The primary material employed in the SAP (Super Absorbent Polymer) industry, particularly in hydrogels for agricultural purposes, is "Potassium Polyacrylate". This is due to its extended water retention capabilities and high effectiveness in soil, without any associated toxicity concerns. These hydrogels are produced by polymerizing acrylic acid with a cross-linking agent. Cross-linked polymers can retain water up to 400 times their own weight and gradually release 95% of it to support plant growth. The utilization of hydrogels leads to heightened water utilization efficiency by preventing water leaching and reducing the need for frequent irrigation.

Water absorption with hydrogel

- Hydrogel acts as water reservoirs in the vicinity of the plant's root zones. When in contact with water, it expands to approximately 200-800 times its original volume, creating ample potential to capture irrigation and rainwater.
- The captured water can then be stored and gradually released to meet the crop's needs over extended periods.
- The incorporation of hydrogel into soil enhances soil permeability and promotes higher germination rates.
- It is adaptable to a wide variety of soil types, generally leading to improved plant performance and increased yields. Moreover, it aids in the retention of rainwater and mitigates soil erosion caused by storm water runoff, particularly on sloped terrain. Evidence also suggests a reduction in fruit and vegetable loss due to insect infestations, by roughly 10-30%.

Specific applications of Hydrogel in agriculture

- Conservation of agriculture land
- Reduction of drought stress
- Improve fertilization efficiency
- Effect on water holding capacity of soil

Conservation of agriculture land

Incorporation of hydrogel polymer can enhance soil's water retention capacity by 50-70% when appropriately adjusted with various ratios of soil to hydrogel. This adjustment also results in a reduction of soil bulk density by around 8-10%. As the dosage of hydrogel increases, there is a noticeable rise in the saturated water content of the soil. This trend indicates a significant improvement in agricultural water utilization efficiency, especially in arid and semi-arid regions, which in turn positively affects the overall plant yield. Hydrogel has a direct impact on various soil properties, including permeability, density, structure, texture, evaporation, and water infiltration rates. It results in reduced irrigation frequency, diminished compaction tendencies, and decreased water run-off. Furthermore, it promotes soil aeration and enhances microbial activity.

Reduction of drought stress

Drought stress can trigger the generation of oxygen radicals, leading to heightened lipid peroxidation and oxidative stress in plants. This stress is visible through signs such as reduced plant height, decreased leaf area, and damage to the foliar matrix. Hydrogel has the capacity to diminish the adverse effects of drought on plants, resulting in reduced stress and oxygen radical formation. Consequently, it creates opportunities for improved growth and yield, even in unfavorable climatic conditions.

Improve fertilization efficiency

Irrigation technology faces significant limitations in the application of fertilizers, herbicides, and pesticides. Research indicates that the adoption of hydrogel agriculture can substantially decrease the need for synthetic fertilizers, all while maintaining crop yields and nutritional quality. This approach is well-suited for sustainable agriculture, especially in arid and semi-arid areas and regions with similar environmental challenges. Furthermore, the use of "**potassium polyacrylate"** is environmentally safe and non-toxic, contributing to the prevention of pollution in agricultural ecosystems.

Effect on water holding capacity of soil

Typically, sandy soil has a limited capacity to retain water. Hydrogels provide significant advantages when applied to sandy soil, enabling the achievement of optimal crop yields regardless of climatic conditions. In a study conducted by Johnson (1984), different cross-linked polyacrylamides were mixed with sand, resulting in a polymer concentration range of 0–2 g/kg. The findings demonstrated that all tested polymers considerably increased the field capacity (FC) of coarse sand, by 171% and 402%. Furthermore, Johnson's research revealed that the permanent wilting point (PWP) was reached in the control sand within 2–3 days, while it extended to 6–7 days for sand treated with 1 g/kg of polymer and 9–10 days for sand treated with 2 g/kg of polymer.

Application rate of hydrogel in soil

- 4-6 g/kg soil in arid and semi-arid region
- 2. 25-3 g/kg soil in all level of water stress treatment and improved irrigation period
- 0.2-0.4 g/kg or 0.8% of soil whichever is more for delay permanent wilting point in sandy soils
- 0.5-2.0 g/pot used to improve relative water content and leaf water use efficiency
- 0.2-0.4 % of soil applied to reduce drought stress
- 225-300 kg/ha of cultivated area for totally prohibit drought stress
- 3% by weight for reduce drought stress

(Source:http://vikaspedia.in/agriculture/best-practices/sustainable-agriculture/cropmanagement/hydrogelagriculture-technology)

CONCLUSION

Hydrogel proves to be a valuable asset for dry farming, especially considering that a significant portion of India's land is situated in arid and semi-arid regions. Given the pressing need for more efficient water use in agriculture, adopting proper management practices to preserve soil moisture and enhance water retention is crucial. Super absorbent polymers (SAPs) in the form of hydrogels have the remarkable ability to expand and absorb substantial volumes of water or aqueous solutions. This unique property has led to numerous practical applications, particularly in agriculture, where it significantly improves soil water retention and supports plant hydration.

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