Hydrogels: A Smart Approach for Sustainable Agriculture

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ABSTRACT

Increasing water scarcity and the increasing population of the world pose many challenges to sustainable agriculture practices. Hydrogel is a type of material that can be used due to its ability to absorb, retain, and slowly release nutrients and water. In regions where there is a scarcity of water, hydrogel helps crops withstand drought and facilitates growth by retaining soil moisture. Moreover, they play an important role in controlling release of nutrients in agriculture and thereby reducing pollution. Using hydrogels with seeds helps crops grow even in stress conditions. They are also beneficial in contemporary agricultural methods like hydroponics and improving soil properties. Nevertheless, several challenges are associated with synthetic hydrogels such as their exorbitant costs and lack of knowledge among farmers about them.

INTRODUCTION

The world population is projected to reach almost 10 billion by the year 2050. This will increase pressure on agriculture for higher food production using lesser inputs. Meanwhile, water shortage issues have become severe as agriculture consumes over 70% of the freshwater, owing to climatic changes and increasing water

demand. Water and food production needs to expand rapidly to meet future requirements. Nevertheless, agricultural output has been severely affected by water shortage problems in many regions. Droughts, salinity, and temperature variations are some examples of environmental stress that hamper agricultural productivity. Furthermore, desertification has intensified due to climate changes and resulted in low food production. Though drip irrigation and sprinkler irrigation are some examples of irrigation technology that saves water in contemporary times, their prohibitive prices make it hard for farmers to adopt them on a wide scale. Meanwhile, there is a necessity for the application of fertilizers and pesticides because diseases and pests still pose serious threats to crops around the globe. Environmental pollution, poor soil quality, and nutrient inefficiency have been consequences of this phenomenon. There is an urgent need for sustainable agriculture practices to ensure a balance between environmental security and efficiency, which is the only way to get past these challenges. Diversification in agricultural production and cultivation of better varieties can support such efforts (Elshafie, 2021). Hydrogels are materials that can store water, and when released slowly, can prove helpful in this regard.

Hydrogel Requirement

The difficulty with the formation of soil conditioners having an enhanced biodegradation period can be considered the most complicated challenge in agriculture. The optimal way out of the above-mentioned problem is considered the formation of "hydrogel." At present, all aspects, including lighting, nutrition, and growing media, are undergoing modifications in modern sustainable farming (Ali *et al*., 2024). Among many others, the question of water resources becomes a subject of research due to its great importance for plants. Hydrogel plays the role of one of the leading materials used in agriculture.

Types of Hydrogels Utilized in Agriculture

- Natural hydrogels: derived from cellulose, starch, and chitosan (decomposable and eco-friendly).
- Synthetic hydrogels based on polyacrylamide: very efficient yet detrimental to the environment.
- Hybrid hydrogels: combination of both synthetic and natural components.

Properties of Hydrogels

Some of the most important properties of hydrogels which are relevant to their use in agriculture include water absorption capability, mechanical strength, biodegradability, and environmental response. They can absorb large quantities of water, with the degree of cross-linking affecting the level of mechanical stability and water retention. Hydrogels with lower degrees of cross-linking will have greater water absorption ability but lack stability while hydrogels with high degrees of cross-linking will have higher levels of mechanical strength and durability.

Eco-friendly hydrogel applications in sustainable agriculture

1. Soil Moisture Retention and Drought Prevention

Where water availability is low, environmentally friendly hydrogels play an important role in enhancing the moisture content of the soil. By retaining large quantities of water whenever there is watering or rain and slowly releasing it when the soil becomes dry, they act like small-scale reservoirs (Neethu *et al*., 2018). This ensures that the plants receive sufficient water supply steadily and helps minimize the effects of drought, thus improving the chances of their

survival. They also help minimize water loss from deep percolation and evaporation.

2. Controlled Release of Nutrients and Agricultural Chemicals

The use of hydrogels can help control the release of nutrients, making fertilizers more efficient. These hydrogels retain nutrients and release them according to soil moisture; conventional fertilizers, on the other hand, often tend to lose a lot of nutrients due to leaching and running off. This ensures that plants get the necessary nutrients during their growing periods in a consistent manner. Consequently, repeated use of fertilizers is not required, thereby reducing environmental contamination and maximizing nutrient usage.

3. Coating Seeds and Improving Germination

Hydrogels have become increasingly popular for coating seeds to boost germination rates. Hydrogels provide an external coating for seeds, which provides nourishment and stores water during germination.

4. Improvement and Remediation of Soil

The role played by hydrogels is very important in enhancing the general wellbeing and physical state of the soil. Their properties of swelling and contraction are known to enhance water infiltration, aeration, and porosity of the soil. Hydrogels further play an important role in ensuring that soil particles are bonded well, thus reducing erosion from water and wind action.

CONCLUSION

Hydrogels have vast potential in sustainable agriculture by virtue of their properties that improve soil moisture retention, soil water utilization efficiency, and soil quality in general. Though there are problems with synthetic hydrogels in terms of high cost and adverse effects on the environment, the use of hydrogels made of natural polymers such as starch, cellulose, and chitosan is eco-friendly. There is no doubt that hydrogels can tremendously enhance the agricultural yield and water resource management, even with their downsides such as high manufacturing costs and mechanical weakness. Hydrogels will undoubtedly play a critical role in achieving sustainable food security through continued research and innovation.

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