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Email

shuaibuusmanm21@gmail.com

APPLICATION OF HYDROGEL TECHNOLOGY IN SUSTAINABLE SOIL WATER MANAGEMENT FOR CLIMATE-RESILIENT FARMING IN ARID AND SEMI-ARID AREAS

¹Usman Shuaibu Majikumna* and ¹Kunal Narwal

¹Sanskaram University, Jhajjar, Haryana (124108), India

Climate change is making water scarcity, unpredictable rainfall, and soil degradation even worse in dry areas, which poses serious risks to farming and food security. That's why sustainable soil water management is crucial for farming systems that can withstand climate challenges. One exciting development in this area is hydrogel technology, especially the use of superabsorbent polymers (SAPs). These materials are proving to be a game-changer for keeping soil moist and boosting crop yields in drought-prone regions. Hydrogels are unique three-dimensional polymers that can soak up and hold a lot of water, releasing it slowly to plant roots as needed. When used in agricultural soils, they enhance water efficiency, cut down on how often irrigation is needed, reduce nutrient loss, and improve soil characteristics like porosity and stability. In dry environments where evaporation is high and rain is scarce, hydrogels help create the right moisture levels for seed germination, root growth, and overall crop development. Research has shown that integrating hydrogels with climate-smart farming practices can lead to significant yield increases in crops like pearl millet, maize, wheat, and various vegetables. Plus, there are biodegradable and eco-friendly hydrogels made from natural materials that provide sustainable options, helping to alleviate concerns about synthetic polymers piling up in the soil. However, there are still hurdles to overcome, such as high production costs, inconsistent performance in the field, and a lack of awareness among farmers, which can slow down widespread use. This review sheds light on how hydrogel technology can play a vital role in sustainable soil water management and its potential to support climate-resilient agriculture in areas facing water stress. Wider adoption, backed by research, policy changes, and educating farmers, could really boost agricultural sustainability and resilience as we face shifting climate conditions.

Water scarcity poses a significant challenge to agricultural productivity, especially in arid and semi-arid regions around the globe. With climate change ramping up the frequency of droughts, causing erratic rainfall patterns, and increasing evapotranspiration rates, we're seeing

a troubling decline in soil moisture and crop yields (Oladosu et al., 2022). This makes sustainable soil water management crucial for boosting agricultural resilience and securing food supplies in the face of shifting climate conditions. Enter hydrogel technology, which has become a game-changer for conserving soil moisture in dry land farming. These superabsorbent polymer materials can soak up impressive amounts of water and then slowly release it to plant roots when they need it most (Krasnopeeva et al., 2022). By using hydrogels, farmers can enhance soil water retention, cut down on how often they need to irrigate, and improve crop performance even when water is scarce. Recent research has sparked a growing interest in eco-friendly and biodegradable hydrogels, thanks to their potential benefits for climate-smart agriculture. Not only do these hydrogels help retain soil moisture, but they also minimize nutrient leaching, enhance soil structure, and boost water-use efficiency (Li et al., 2022).

Agricultural Hydrogels and Their Functions

Hydrogels are fascinating three-dimensional networks of hydrophilic polymers that can swell up when they come into contact with water, all without dissolving. In the agricultural world, hydrogels are typically categorized into three types: synthetic, natural, and hybrid. Synthetic hydrogels are often made from polymers like polyacrylamide and polyacrylate, which are known for their impressive water absorption capabilities and durability in soil (Adjuik et al., 2022). On the other hand, natural hydrogels come from biodegradable sources such as starch, cellulose, chitosan, and alginate. These options are not only eco-friendly but are also gaining popularity in sustainable farming practices because they help minimize the environmental risks linked to synthetic materials (Li et al., 2022).

Hybrid hydrogels, as the name implies, blend both synthetic and natural polymers to enhance their water retention, biodegradability, and nutrient release features. Think of hydrogels as tiny water reservoirs nestled in the soil. When it rains or during irrigation, they soak up and store water, which they then release slowly to the plant roots during dry spells. This clever mechanism plays a crucial role in keeping soil moisture levels stable in the rhizosphere, ultimately helping to shield plants from drought stress (Krasnopeeva et al., 2022).

Role of Hydrogels in Soil Moisture Management

Hydrogels are incredibly important for boosting the water-holding capacity of soil, particularly in sandy areas that often struggle with low organic matter and poor moisture

retention. When added to the soil, they enhance its porosity, aggregation, and infiltration, which ultimately makes more water available for crops (Oladosu et al., 2022). Research has shown that using hydrogels can significantly cut down on evaporation losses and improve how efficiently water is used. According to Adjuik et al. (2022), both bio-based and synthetic hydrogels have been found to enhance soil hydraulic properties by increasing water retention and minimizing losses from evaporation and deep percolation. Moreover, hydrogels play a key role in better nutrient management by reducing nutrient leaching and boosting fertilizer efficiency.

The water stored in hydrogels can dissolve nutrients and release them gradually along with moisture, ensuring that plants have a steady supply of nutrients (Li et al., 2022). In areas prone to salinity and drought, hydrogels can alleviate moisture stress and support better crop establishment. Tefera et al. (2022) noted that biomass-based hydrogels improved water retention and lessened salinity stress in salt-affected soils, which is vital for sustainable crop growth.

Hydrogels and Climate-Resilient Agriculture

Climate-resilient agriculture is all about boosting the ability of farming systems to adapt to climate-related challenges like drought and unpredictable rainfall. One exciting way to enhance this resilience is through hydrogel technology, which helps conserve soil moisture and keeps crop productivity steady even when water is scarce (Oladosu et al., 2022). Hydrogels play a crucial role in improving seed germination, root growth, and plant survival by ensuring that there's enough moisture around the roots during dry spells. This is especially vital in arid and semi-arid areas where irrigation options are limited and rainfall can be hit or miss (Krasnopeevea et al., 2022). Using hydrogels can also mean less frequent irrigation and better conservation of our precious freshwater resources. With reduced irrigation needs, farmers can save on production costs and cut down on the energy used for irrigation systems. Plus, hydrogels can work hand-in-hand with controlled-release fertilizers and precision irrigation technologies, making agriculture more sustainable overall (Venkatachalam & Pushparaju, 2022). However, there are still some hurdles to overcome before hydrogel technology can be widely adopted. For instance, synthetic hydrogels can linger in the soil for a long time, potentially leading to environmental pollution. On top of that, the high production costs can make it tough for smallholder farmers to access these technologies (Adjuik et al., 2022). That's

why current research is focused on creating low-cost, biodegradable hydrogels made from renewable materials to support sustainable farming practices.

Conclusion

Hydrogel technology is an exciting solution for managing soil water sustainably, especially in arid and semi-arid areas that are grappling with climate change and dwindling water supplies. By boosting soil's ability to hold moisture, enhancing how efficiently water is used, and helping crops thrive even during droughts, hydrogels play a crucial role in creating farming systems that can withstand climate challenges. When combined with climate-smart agricultural practices, they can lower irrigation needs, improve soil health, and bolster food security in at-risk regions. While there are still hurdles to overcome, such as costs, accessibility, and potential long-term environmental impacts, ongoing research, technological progress, and educational initiatives for farmers can pave the way for broader use of hydrogel technology in sustainable agriculture.

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