APPLICATION OF RADIATION POLYMERIZED SUPERABSORBENT HYDROGEL ON PLANT GROWTH AND PRODUCTIVITY

Kuber C. Bhainsa, Debaparna Dutta and Tapan K. Ghanty
Nuclear Agriculture and Biotechnology Division,
Bio-Science Group, Bhabha Atomic Research Centre, Mumbai-400085, India.

Email: tapang@barc.gov.in; kuber@barc.gov.in

Abstract:

Water is the most important natural resource for sustainable crop production and food security. Water availability in our country is dependent on the monsoon to grow major crops, including plantation crops. However, climate change and global warming has affected the rainfall patterns, causing prolonged shortages of water and increased average temperatures in the environment, leading to drought and arid conditions in many areas. This has not only compromised food security but also affected the livelihood of farmers engaged in agriculture, horticulture and plantation. To address the issue of efficient use of available water, Bhabha Atomic Research Centre, Mumbai has come out with a product, the superabsorbent hydrogel, developed using gamma irradiation, thereby avoiding the use of harmful chemical cross-linkers. It can absorb and retain water up to several hundred times (>550 times) of its own weight and maintains slow and sustainable release of water supporting plant growth. Application of the hydrogel enhances soil moisture levels and improves plant health and productivity in arid, semi-arid, and drought conditions. Reduction in the need for frequent irrigation can save water and increase coverage of cultivable areas. At the same time, sustained water release from hydrogels can improve yield and increase farmer's income.

Due to its rapid and high-water absorption capacity, hydrogel can be used in various agriculture and horticulture applications including plantation agriculture, landscaping, vertical gardening, terrace gardening, root dipping etc. Other major applications of the hydrogel can be in plantation and afforestation programs to improve survival of sapling in the initial stages. These outcomescan reduce the total duration required for making green zone

along highways and afforestation. Deployment of this technology can be done through the National Highway Authority of India (NHAI), Ministry of Environment, Forest and Climate Change for plantation along highways and the Ministry of Agriculture and Farmers Welfare.

Introduction:

Hydrogels are three-dimensional, hydrophilic polymer networks capable of absorbing and retaining large amounts of water. Their unique properties make them versatile materials with applications in various fields. A comprehensive review by Lee and Mooney (2012) highlights the significance of hydrogels in biomedical applications[1]. Hydrogels are extensively employed in drug delivery systems, providing controlled release of therapeutic agents to targeted sites[2]. Additionally, their biocompatibility and tunable mechanical properties make hydrogels suitable for tissue engineering and regenerative medicine[3]. Hydrogel-based sensors showcase their utility in wearable devices, providing real-time monitoring of physiological parameters[4]. Moreover, hydrogels find applications in agriculture for soil moisture retention and environmental remediation due to their water-absorbing capabilities[5]. These examples underscore the wide-ranging applications of hydrogels, emphasizing their impact on drug delivery, tissue engineering, sensing technologies and environmental sciences.

Hydrogels exhibit diverse compositions and structures, leading to their classification into several types. Natural hydrogels, derived from biological sources like alginate and chitosan, offer biocompatibility. Synthetic hydrogels, such as polyacrylamide and polyvinyl alcohol, provide tunable properties for specific applications. Responsive hydrogels, like temperature-sensitive and pH-sensitive hydrogels, undergo structural changes in response to environmental stimuli. Hybrid hydrogels combine both natural and synthetic components, harnessing the advantages of both. Smart hydrogels exhibit responsiveness to external stimuli, making them suitable for controlled drug delivery and tissue engineering applications[6].

In agriculture, hydrogels play a pivotal role in water management (Fig.1). The use of hydrogels can enhance water retention in soil[7]. These hydrogels, when incorporated into the soil, absorb and retain water, gradually releasing it to plants, thereby improving water-use efficiency. This technology is particularly crucial in arid and water-scarce regions, promoting sustainable agriculture[8]. Furthermore, hydrogels can enhance nutrient delivery to plants fostering improved crop yields[9]. Additionally, hydrogel-based formulations can act as carriers for controlled release of pesticides and fertilizers, reducing environmental impact and optimizing resource utilization[10]. In summary, hydrogels offer innovative solutions in agriculture by addressing water scarcity, enhancing nutrient delivery, and providing a sustainable approach to soil management.

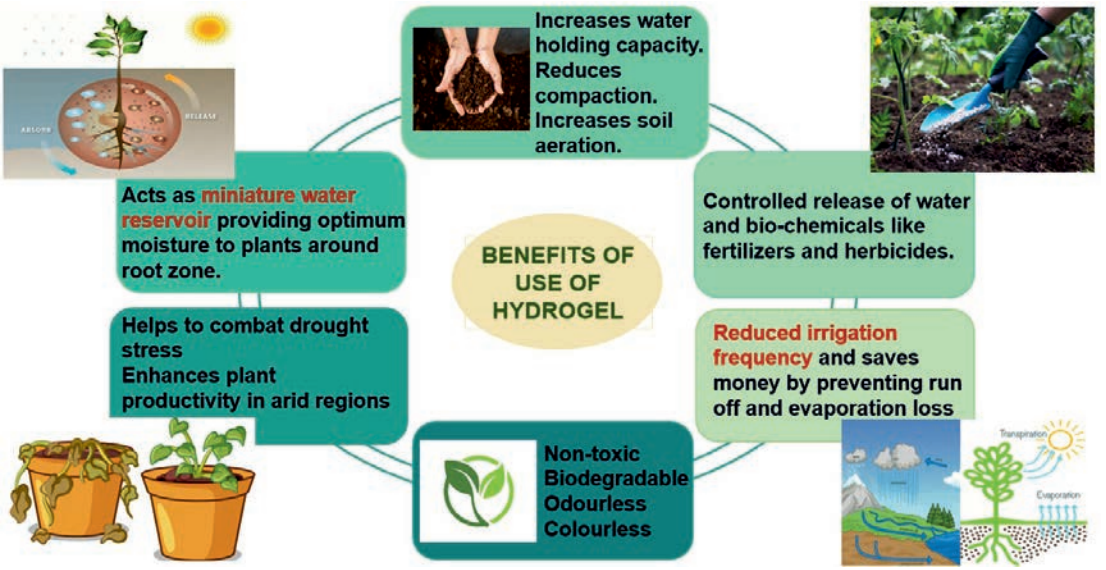
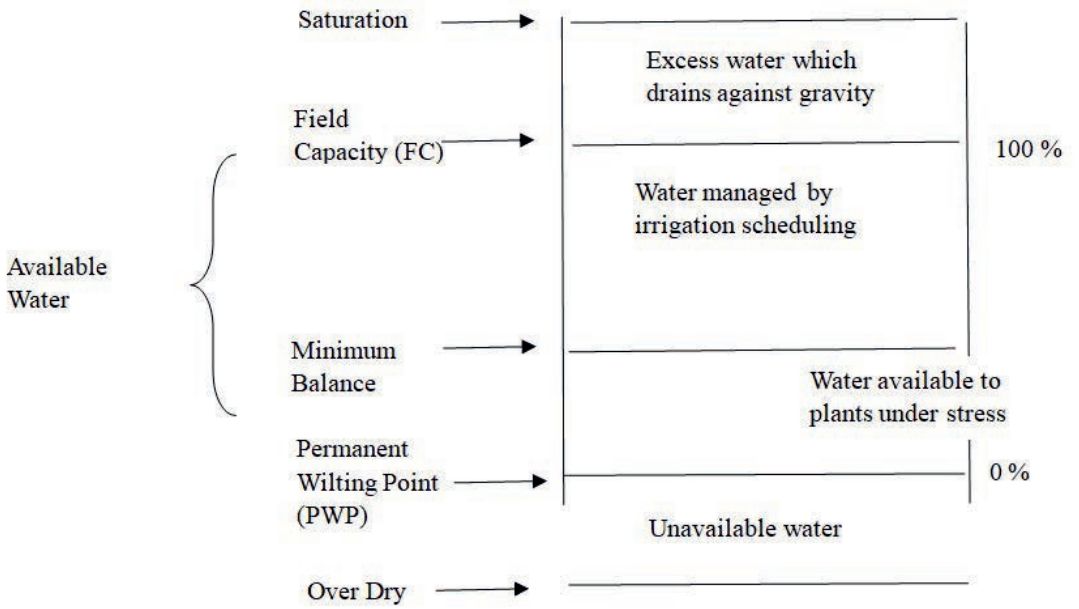


Fig. 1: Benefits of Hydrogel in Agriculture

Irrigation required for food production based on soil types:

Moisture content for different types of soils varies as shown in the chart below. Irrigation practices during cultivation require appropriate adaption of technologies to save water.



Source[12](Gavrilescu and Maria, 2021)

Typically, sandy soil holds lesser moisture (7%) in comparison to clay which can hold up to 31% moisture (Table.1). Irrigation frequency required for sandy soil is more for cultivation of crops. Further, Table 2 shows water required for unit amount of food products indicating value of saving water.

Table 1. Water consumption for production of foodstuff

Foodstuff	Quantity	Water consumption, litres
Chocolate	1 kg	17,196
Beef	1 kg	15,415
Sheep Meat	1 kg	10,412
Pork	1 kg	5,988
Butter	1 kg	5,553
Chicken Meat	1 kg	4,325
Cheese	1 kg	3,178
Olives	1 kg	3,025
Rice	1 kg	2,497
Cotton	1@ 250g	2,495
Pasta (dry)	1 kg	1,849
Bread	1 kg	1,608
Pizza	1 unit	1,239
Apple	1 kg	822
Banana	1 kg	790
Potatoes	1 kg	287
Milk	1× 250 ml glass	255
Cabbage	1 kg	237
Tomato	1 kg	214
Egg	1	196
Wine	1× 250 ml glass	109
Beer	1× 250 ml glass	74
Tea	1× 250 ml cup	27

(Source: Eye on Environment, 16 June, 2016)

The ever-increasing demand for the increased food production would require more and more water for agriculture (Table 2). As can be seen, the production of 1 kg of rice requires as much as 2497 litres of water, whereas for 1kg of apple the water required is 822 litres. This shows how water can determine the fate of food production and how saving water can improve food security. In view of this, application of hydrogel would play an important role, and hence investigating its role in improving plant growth and productivity is very important. The current study gives an account of application of hydrogel in various crops, including fruits, flowers, vegetables, and tree plantations.

Processing of hydrogel:

Refrigerated pilot-scale precursor solution preparation unit (maximum capacity: 30 litres) is shown in Fig 2. The solution was irradiated using gamma radiation (6 kGy). In-house processing of irradiated wet hydrogel mass has been demonstrated successfully, which includes manual cutting/chopping, drying, grinding and sieving to achieve defined-size hydrogel particulates (sizes ranging from 500 microns to 1 mm) (Fig.2).

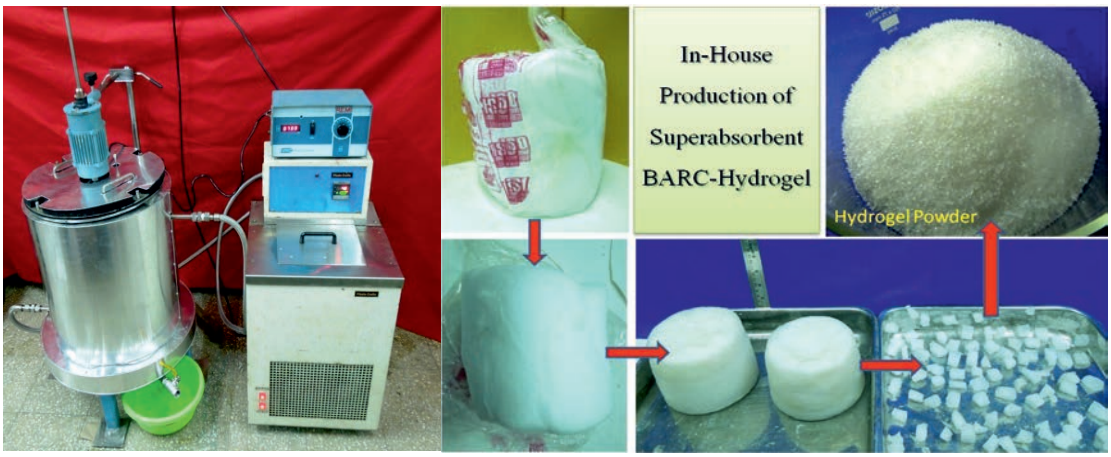


Fig. 2: In house production of hydrogel

Application of hydrogel:

Laboratory study without soil:

Laboratory trials on seedlings of A. monocot rice and B. dicot gram seeds under soil-less conditions were conducted to demonstrate the hydrogel support with no adverse effect (Fig 3).

A. Rice

B. Gram

Fig. 3: Result showed that hydrogel could support germination and growth of both monocot and dicot plants. Based on these results, studies were further extended to pot study involving other crops.

Application of hydrogel in pot study:

1. Flower crops: Marigold:

Figure 4 shows a low flower yield in poor or low porosity control soil, while hydrogel added soil exhibited improved porosity and moisture level, which allowed higher root development, shorter root length and better flower yield in comparison to control (Fig. 4).

Fig. 4: Results of pot experiments conducted with different hydrogels.

2. Ornamental crops: Lemon croton

Hydrogel trial on Lemon Croton plants under arid conditions (i.e. irrigation was performed once in a week), wherein two different concentrations of hydrogel (i.e., [A] 1 % & [B] 0.5% and 1%) were used in soil (A). Figure (B) shows the higher growth and survival of hydrogel-treated plants at two different concentrations compared to the control (images were taken after one year) (Fig 5).

Fig.5. Effect of hydrogel on survival and growth of Lemon Croton

Field application of hydrogel:

1. Vegetable crop, Okra:

Higher germination and growth of Okra plants in hydrogel- treated soil (left) was seen compared to control soil, i.e., no hydrogel was used (right) (Fig.6A). Moreover, the vegetative growth of plants was also found to be improved in the hydrogel-treated plants, as shown in figure (Fig. 6B).

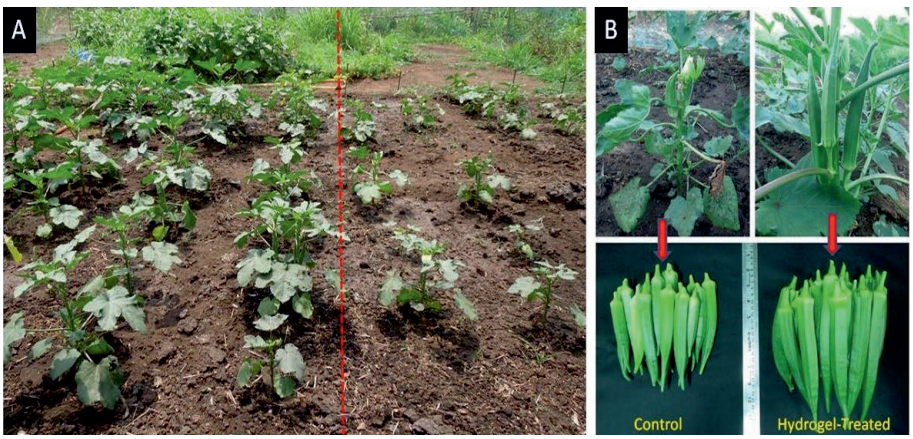


Fig. 6. Effect of hydrogel on growth and productivity of Okra.

2. Hydrogel for application in Madhuban (Urban forest based on MIYAWAKI concept: Plantation of Medicinal plants):

In an open area of 1000 square meters 25 kg hydrogel was applied and medicinal plants were grown as per the details given below:

3.5 Plants per sq.m., No. of trees – 2400, No. of Species – 38, Max Height of Tree – 25 Feet, Area of Plantation – 1000 sq.m., Total Area– 1750 sq.m.

Field view in December 2020

Fig. 7. Field view showing luxurious growth of medicinal plants, Upper panel: Dec 2020, Lower panel July 2021.

3. Application in fruit crops at SKUAST-K, Srinagar:

Current result on application of hydrogel (100g/tree) on fruit crops such as pear, cherry and nectarine at Sher-E-Kashmir University of Agriculture, Science and Technology-Kashmir (SKUAST-K), Srinagar, showed excellent results (Fig. 8) in terms of lower cracking of fruits and up to 120 % higher yield. These results were achieved with only one irrigation in treated plant (N=15 trees per group; duration: one year). On the contrary, there was more than 60% loss of crops in control plants with low yield even after applying two irrigation.

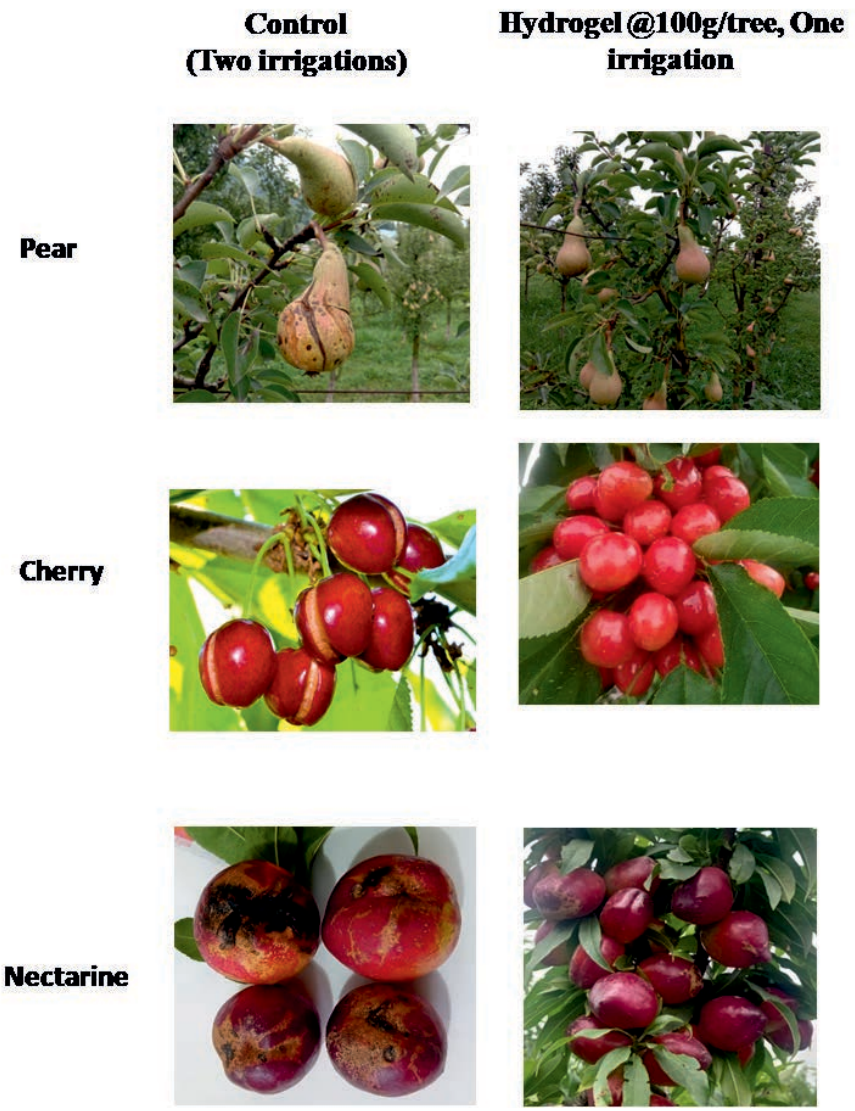


Fig. 8. Application of hydrogel during onset of fruiting on 7 years old plant in the fruit orchard prevented cracking of fruits and improved yield

The current status of the technology:

In total, this technology has been transferred to eight private entrepreneurs. M/s Crimson Energy Experts Pvt. Ltd., has established the manufacturing facility at Vasai, Maharashtra, and started manufacturing the product under the brand name 'Amrut Hydrogel'. It is available for sale on major e-market sites such as Amazon, Flipkart, and GeM.

Conclusions:

The availability of limited fresh water for agriculture poses a great challenge for the future of food security. This is compounded by irregular and erratic rainfall in many parts of our country and around the globe. The current study shows that the application of Hydrogel during agriculture practice not only saves water but also improves productivity. However, adaptation of new technologies will depend on improved awareness of the benefits of the product in real field conditions and effort needs to be made in this direction.

Reference:

1. Lee, K. Y., & Mooney, D. J. Hydrogels for tissue engineering. Nature Reviews Materials, 2012, 1(6), 16012.
2. Hoffman, A. S. Hydrogels for biomedical applications. Advanced Drug Delivery Reviews, 2012, 64(18), 18-23.
3. Khansari, S., & Sorokina, L. V., et al. Biocompatible hydrogels in regenerative medicine. Advanced Healthcare Materials, 2018, 7(23), 1800923.
4. Yuk, H., Lu, B., et al. Skin-inspired hydrogel-based sensors. Nature Communications, 2016, 7, 12028.
5. Ahmed, E. M. Hydrogel: Preparation, characterization, and applications: A review. Journal of Advanced Research, 2015, 6(2), 105-121.
6. Stuart, M. A. C., et al. Emerging applications of stimuli-responsive polymer materials. Advanced Drug Delivery Reviews, 2010, 62(4-5), 272-282.
7. Zhang, J., Zhang, M., et al. Hydrogel-based agricultural applications: A review. Journal of Cleaner Production, 2019, 234, 1328-1338.
8. Ahmed, E., Hashish, E. A., et al. Superabsorbent hydrogels for agriculture under climate change scenarios. Science of the Total Environment, 2019, 661, 373-382.
9. Liu, C., Wang, Y., et al. Application of hydrogel for water conservation in agriculture: A review. Agricultural Water Management, 2021, 243, 106466.
10. Alamri, S. A., et al. Hydrogel-based controlled release of pesticides in agriculture: A review. Journal of Agricultural Science and Technology, 2019, 21(5), 1045-1062.
11. Jonathan Trinastic, "Sustainable Practices for a Greener Future." Eye on Environment, 16 June, 2016.
12. Gavrilescu, Maria. “Water, Soil, and Plants Interactions in a Threatened Environment.” Water , 2021, 13(19), 2746.