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PROSPECTS AND APPLICATION OF HYDROGEL TECHNOLOGY IN HORTICULTURE: A REVIEW

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ABSTRACT

The global population is rising at a tremendous rate leading to urbanization which results in deforestation and land degradation ultimately hampering the food production. In order to cope up with the rising problem to feed the ever-growing population with limited resources pose a great challenge to the researchers in this sector. Depleting groundwater resources, scanty rainfall and climate change pattern globally hampers the horticultural crop production. Under such conditions, hydrogel may prove as an alternative and wiser choice to overcome water scarcity problems and enhance overall crop production. In prospect of varied soil type and prevailing agroclimatic condition, use of hydrogel has proved to be effective even at low application rate (2-5 kg/ha). Beside water saving properties, hydrogel has diverse role in improving the physico-chemical and biological properties of soil improving porosity, bulk density and water holding capacity of soils. Hydrogel is the best choice for increasing horticultural crop production with sustainability in scarce water condition since they degrade naturally over a period of time without leaving any toxic residue in soil and crop products.

Key words: Hydrogel, water scarcity, scanty rainfall, sustainability, water holding capacity.

Introduction

Uneven rainfall pattern and water scarcity problems due to climate change scenario has affected agriculture and horticulture sector affecting crop production. Nearly 70% of Indian population relies upon agriculture for their livelihood accounting for 159.7 million ha. India has only 2.45% of the world's land area and 4% of its water resources, despite having 16% of the world's population (Tanuja and Anitha., 2022). In terms of water stress, India is ranked 41st out of 181 nations worldwide accounting for more than 60% net cultivated area under dryland cultivation (Dar *et al*., 2017). Agriculture is under abiotic stresses (drought, salinity and temperature) which is likely to increase due to land degradation, urbanization and climate change. India ranks 41st in water stress since most of the area is located in arid and semi-arid regions. India accounts for 2.45% of land area and 4% of water resources of the world, witnessing 16% of the world's population. Increasing food demand with ever growing population and declining water resources pose major challenge for food security, Kreye *et al*., (2009). With limited and depleting water resources the world is looking for water-efficient agriculture. Crop yields will undoubtedly be significantly impacted by water shortage because water resources are already running out far more quickly than they would naturally replenish. Even after proper management practices to conserve soil moisture and increase water holding capacity of the soils, the crop yield is tremendously affected. The most alternative and best solution to the addressed problem is hydrogel. Hydrogels were introduced in the early 1980's for agricultural use (Narjary *et al*., 2013). Hydrogels' capacity to sustain a consistently controlled water supply is especially advantageous in situations involving water stress, particularly in arid and semi-arid areas (Kaur *et al*., 2023). As per reports, water scarcity is defined as a situation where the amount of water available per person is less than 1000 m^3, while water stress is defined as a situation where the amount of water available per person is less than 1700 m^3. It is evident from Table 1 that India

Table 1: Average annual per capita availability of water in India. **[Source: Report by UNICEF, 2013].**

Year	Population (million)	Per capita water availability (m^3/year)
2001	1029	1816
2011	1210	1545
2025	1394	1340
2050	1640	1140

is heading towards becoming a country with water scarcity conditions.

Hydrogels are hydrophilic gels made of cross-linked polymers that can absorb a lot of water without breaking down. The water storage capacity and its softness is what makes hydrogel exceptional (Shibayama and Tanaka., 1993). Hydrogel are often referred to as plant gel or super absorbent polymers. It does not dissolve in water due to cross-linked polymers but without cross-linkage it can be dissolved in water. Hydrogel can absorb more than 400-500 times water by its dry weight. Hydrogel progressively releases up to 95% of the water it has stored when its surroundings start to dry out. Re-exposure to water will cause it to rehydrate and go through the water-storage process again. This process can last up to 2-5 years, by which time biodegradable hydrogel decomposes. Water absorption rate depends on the structure of hydrogel and quality of water. Hydrogels can absorb and hold both irrigation and rain water. In turn, the use of both capillary and gravitational water helps to lessen deep percolation. The hydrogel progressively releases up to 95% of its stored water when the surrounding media area dries out. Agricultural hydrogels are also referred to as water retention granules because they swell to many times their original size when they come into contact with water.

Hydrogel forming natural polymers include polysaccharides like agarose and alginate as well as proteins like collagen and gelatin. Hydrogels formed from synthetic polymers are prepared traditionally by using chemical polymerization methods. Hydrogel is a single polymer molecule, meaning that the network chains within the gel are joined to form a single, large molecule at the macroscopic level. The words hydrogel and gel which are neither entirely liquid nor entirely solid are frequently used interchangeably. Numerous intriguing relaxation behaviors that are absent from both pure liquid and pure solid states are brought about by these semi-liquid and semi-solid-like properties. When exposed to specific external stimuli, such as temperature, solvent quality, pH, electric field, etc., hydrogels can react by displaying sudden changes in volume (Tanaka.,1978).

General uses of hydrogel

Due to their excellent properties and large water absorption capacity, hydrogels are used in many products having importance in our daily life including diapers (Neethu *et al*., 2018), hair gels, sanitary napkins, sweat soaking body powder, sealing, artificial snow (Singh *et al*., 2010), drug delivery systems and agriculture (Hamidi *et al*., 2009) , pharmaceuticals (Kashyap *et al*., 2005), biomedical applications (Stamatialis *et al*., 2008), tissue engineering and regenerative medicine (Saul and Williams., 2011), wound dressing material, separating cells or biomolecules from barrier materials to control biological adhesion.

Water absorption mechanism of hydrogel

Water absorption in hydrogels is caused by hydrophilic groups of the polymer chain, such as carboxy acid, acrylamide, acrylate, and acrylic acid, which are joined to the main chain of the polymer. When these polymers are immersed in water, the water osmotically enters the hydrogel system, where hydrogen atoms react and release positive ions that leave behind negative ions along the polymer chain. As a result, there are several negative charges along the hydrogel's length that repel one another, causing the polymer chain to unwind and open up. Additionally, they draw in water molecules and

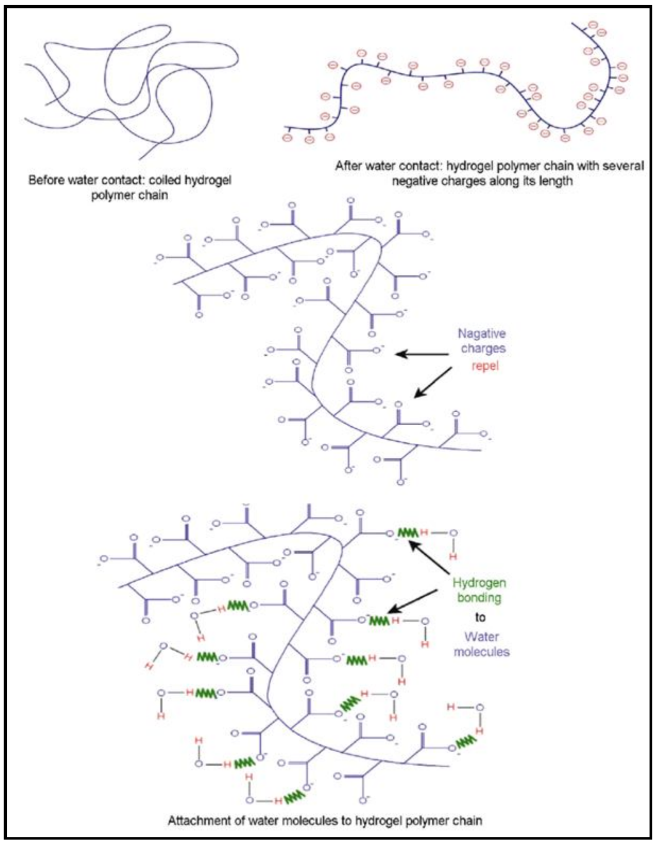

Fig. 1: Water absorption mechanism of hydrogel (Source Kalhapure *et al*., 2016).

Table 2: Characteristic and potential applications of Hydrogel **(Source: Kalhapure *et al*., 2016).**

S. No.	Parameter	Characteristic and potential applications
1.	Chemical constitution	Cross linked anionic polyacrylate
2.	Appearance	Amorphous granules
3.	Particle size	20-100 mesh (micro granules)
4.	pH	7.0-7.5
5.	Stability at 50^{O}C	Stable
6.	Sensitivity of UV light	Not sensitive
7.	Temperature	40-50 °C
8.	Stability	~ 2 Years

form hydrogen bonds with them. (Vicky, 2007). In this mode, hydrogel can absorb more than 400–500 times its weight in water. Hydrogel progressively releases up to 95% of its stored water when the surrounding environment starts to dry out. It will then rehydrate and begin the water storage process again when it is exposed to water. This process repeats and last up to 2-5 years until the biodegradable hydrogel decomposes.

Use of hydrogel in agriculture

Agricultural hydrogels are artificial polymers that can absorb water many times their own weight and can be used to increase the soil's capacity to absorb water in arid areas. It is therefore referred to as Super Absorbent Polymer (SAP). These hydrogels are more biodegradable and therefore safer to the environment, Fidelia and Chris, (2011). Water absorbing and water retention ability of hydrogel makes it unique choice finding numerous applications in agriculture. It can be used for all crops and all soil types. Hydrogel is a simple solution for crops that need a lot of water and are susceptible to moisture stress, it can be used directly in the soil at the time of sowing and in the growth medium for nursery plantation and pot cultures. Improvement in overall crop productivity with the application of hydrogel have been found to be beneficial in horticultural crops like fruits, vegetables, ornamentals, spices, plantation crops, medicinal and aromatic.

Key Characteristics of Agricultural Hydrogel

- Agricultural hydrogels are natural polymers with a cellulose backbone that are suitable for semi-arid and arid regions because of their high absorbency at temperatures between (40-50°C).
- The composition of soil, nutrient availability and the action of other agrochemicals such as fertilizers, herbicides, fungicides, insecticides, etc., are all unaffected by hydrogel's neutral pH.
- It enhances the physical characteristics of soils (viz. water holding capacity, porosity, bulk density, infiltration rate, soil permeability, etc.) (Bhaskar *et al*., 2013).
- It is found to increase biological/microbial activities in the soil, which in turn increases oxygen/air availability in root zone of the plant (El-Rehim *et al*., 2004).
- Low rates of soil application – field crops require 2.5-5 kg/ha, while nursery horticultural crops require 1-2 kg/ha (Choudhary *et al*., 2014).
- Less impacted when salts are present in its immediate surroundings.
- Hydrogel can absorb 400 times its dry weight in pure water and release it gradually as required by the crop plant.
- The application of hydrogel improves seed germination and the rate at which seedlings emerge because it increases soil porosity, which promotes healthy root growth and density, and reduces soil erosion brought on by compaction.
- Hydrogels help plants tolerate extended moisture stress and lessen the need for frequent crop irrigation by delaying the onset of permanent wilting point and minimizing water loss through evaporation.
- Increase in water and nutrient use efficiency due to extensive root growth.

Application method and rate of hydrogel

The rate at which agricultural hydrogel is applied depends on the texture of the soil; for clay soil it is 2.5 kg/ha (at a depth of 6 to 8 inches) and for sandy soil it can reach 5.0 kg/ha (at a depth of 4 inches). It can be placed just below the root or seed, or in its immediate area, using a need-based application approach. Using a hydrogel and soil admixture in the furrows during the

Fig. 2: Hydrogel soil application (Source Prakash *et al*., 2021).

Table 3: Hydrogel Products Available in India **(Source: Kalhapure *et al*., 2016).**

Trade name	Manufacturing company
Pusa Hydrogel	IARI, New Delhi
Waterlock 93N	Acuro Organics Ltd, New Delh
Agro-forestry water absorbent polymer	Technocare Products, Ahmedabad
Super absorbent polymer	Gel Frost Packs Kalyani Enterprises, Chennai
Hydrogel	Chemtex Speciality Ltd, Mumbai
Rain drops	M5 Exotic Lifesytle Concepts, Chennai

sowing process, root dipping, nursery application, and other techniques are all crucial.

For field crops: Before sowing, a mixture of hydrogel and fine dry soil in a 1:10 ratio should be applied to the opened furrows or combined with seeds or fertilizers. Hydrogel should be placed close to seeds for optimal results.

For transplants in nursery bed: The top two inches of the nursery bed should have a uniform application of a hydrogel mix at a rate of 2 g/m^2 (or the recommended rate). In pot culture, mix 3–5 g/kg of soil before planting.

At the time of transplanting: Mix 2 g (or the suggested rate) of hydrogel per liter of water until the mixture is free-flowing, then let it settle for 30 minutes. Before putting the plant in the field, dip its roots in the solution.

Success stories of Indian farmer's using Hydrogel

A farmer from Udikeri village in the Karnataka Belgaum district named Laxmi Lokkur has tripled her yield in the last two years. Due to water constraints, she used to only cultivate 3-4 acres on her farm; however, she was able to increase that amount to up to 15 acres after she began using hydrogel. Her cotton yield increased to 12 quintals per acre, while her neighbors' yield was 6 to 8 quintals. Her Jowar and wheat yields also yielded comparable results, with her receiving 6 to 8 quintals from each, compared to others' 4 quintals (Attri *et al*., 2022).

Under the Pani Fasal Yojana scheme, Pusa hydrogel was supplied to 1000 farmers in Uttar Pradesh who used it on 300 acres in Barabanki, Faizabad, Shravasti, and Maharajung. Madanchandra Barmi, a farmer from Barabanki, obtained Pusa hydrogel through the Pani Fasal Yojana. He applied Pusa hydrogel to his 2 bigha field out of his 4 bigha field. In the field with Pusa hydrogel, eight irrigations were given, while in the other bigha without Pusa hydrogel, eleven irrigations were given. This reduced the number of irrigations, and the two bighas with Pusa hydrogel produced 24 liters of oil each, while the other two bighas without Pusa hydrogel produced 20 liters of oil (Attri *et al*., 2022).

Table 4: Effects of hydrogel application on consumptive water use in Chrysanthemum [Kumar *et al*., (2005)].

Irrigation number	Water applied/pot (ml)				
	Control	0.5% gel	1.0% gel	1.5% gel	2.0% gel
1	33.8	37.7	40.7	37.6	38.1
2	33.1	39.6	44.6	46.6	38.0
3	36.3	42.4	42.6	46.7	43.6
4	41.9	42.9	44.2	46.7	41.2
5	36.0			52.7	42.4
6	42.9			52.7	47.8
7	47.6				
8	48.0				
9	47.3				
10	47.5				
Total water use/pot (ml)	414.2	162.5	172.5	264.9	257.9

According to a study in the West Himalays on wheat, the number of plants in hydrogel-treated plots rose by 22% more than in non-hydrogel-treated plots. Furthermore, following the hydrogel amendment, both the overall yield and grain yield considerably increased. According to another study on Chrysanthemums, the application of Pusa hydrogel greatly enhanced a number of characteristics, such as the plant's height, spread, number of branches, branch length, and flower stalk length (Boruah *et al*.,2024).

Significant achievements with application of hydrogel in horticultural crops

In ginger, application of 5.0 kg/ha Pusa hydrogel and irrigation interval of 14 days resulted in highest plant height, number of leaves, number of tillers, essential oil percentage and yield of fresh rhizome per plant and per hectare. The findings showed that hydrogel significantly improved ginger's growth, yield, and oil content., Kumar *et al*., (2018).

A substantial increase in pod and leaf yield was achieved by applying 3000 g of hydrogel per hectare to Senna which is one of the most significant and export-oriented crops (Jnanesha *et al*., 2021).

Highest number of quantitative traits was obtained from full irrigation treatment alongwith the consumption of A200 hydrogel in medicinal plant roselle, Sajjadi *et al*., (2021).

Pazderù, K. and Koudela, M. (2013) observed that the hydrogel application (Agrisorb) influenced germination of lettuce and onion seeds. Treated lettuce seeds germinated faster than non-treated control in the beginning of germination process, Impact of hydrogel was tested on *Capsicum annuum* cv Bara for crop productivity and irrigation water use effectiveness. The best growth characteristics were found to be produced by 40% hydrogel and 60% topsoil per plant, indicating that hydrogel can retain water, circulating it into the media and improving the water usage efficiency of pepper crops without compromising plant growth (Hafiz-Afham *et al*., 2023).

Koudela *et al*., (2011) evaluated the influence of Agrisorb, (3 g Agrisorb/l of substrate) added to cauliflower seedlings (cultivar Chambord F1). In addition to significantly increasing marketable yield (by 17.5%), it was observed that the addition of Agrisorb increased the weight of the aboveground parts by 17.3%, the weight of the roots by 28.1%, and the number of leaves by 7.9%.

Dawlatzai *et al*., (2017) reported that Coleus growth and quality were assessed using graduated doses of Pusa Hydrogel (10g, 20g, 30g, and 40g each) combined with 5kg of potting material. The plants' height (38.5 cm), branches (18.1), plant spread (41.6 cm2), stem diameter (1.27 cm), leaves (92.2), and leaf length and width (8.2 and 5.4 cm, respectively) were all significantly greater than those of the control group (without Pusa Hydrogel) 120 days after planting when 40 grams of Pusa Hydrogel were added to 5 kilogrammes of potting media

Conclusion

The world is experiencing climate change, as evidenced by recent instances of sudden weather changes that either increase the frequency of dry spells or cause heavy rainfall, which instead of recharging the groundwater table is lost through evaporation or runoff. Water is a vital element for survival, and it plays a major role in plant growth and yield. Some countries are expected to see a 60% decline in agricultural production by 2050, Hejazi *et al*., (2023). Thus, increasing water use efficiency and making effective utilization of the available water resources are urgent needs. In this case, the innovative technology of using Pusa hydrogel in agriculture opens up new possibilities for preserving soil moisture and resources for coming generations. In areas with limited water resources, hydrogels are a viable and cost-effective solution for boosting agricultural output and environmental sustainability. Fresh water is becoming more and more scarce every day. Moisture conservation techniques, such as the use of Pusa hydrogel, can help address India's extremely low water application efficiency. IARI, Delhi, manufactured it in order to address the issues with synthetic hydrogels. The primary benefit of employing Pusa hydrogel is its capacity to hold water up to 400 times its weight and release it gradually so that plants can absorb it. In order to combat water scarcity and lessen the negative effects of drought stress, hydrogel helps improve soil water absorption and retention.

References

Attri, M., Qurat-ul-ain-aga, Bochalya R.S. and Mehta S. (2022). Role of Hydrogel in Indian Agriculture. *The Agriculture Magazine*. **1(2)**, 27-31.

Bhaskar, N., Aggarwal P., Kumar S. and Meena M.D. (2013). Significance of hydrogel and its application in agriculture. *Indian Farming*. **62(10)**, 15-17.

Boruah, P.J., Kalita R., Routh M. and Goswami P. (2024). Pusa Hydrogel, A Novel Technology to Tackle Water Stress. *Vigyan Varta*. **5(9)**, 80-82.

Choudhary, S.K., Jat A.L., Upadhyay P.K. and Singh R.K. (2014). Hydrogel, The potentialities to produce more crops per drop in agriculture. *Popular Kheti*. **2(4)**, 154-8.

Dar, S.B., Mishra D., Zahida R. and Afshana B.B. (2017). Hydrogel, To enhance crop productivity per unit available water under moisture stress agriculture. *Bulletin of Environment, Pharmacology and Life Sciences*. **6(10)**, 129-135.

Dawlatzai, A.S., Jayanthi R. and Abdiani S.A. (2017). Efficacy of graded doses of Pusa Hydrogel on growth and quality of coleus (*Coleus blumei* L.) under polyhouse condition. *International Journal of Agriculture & Environmental Science*. **4(4)**, 33-38.

El-Rehim, H.A., Hegazy E.S.A. and El-Mohdy H.A. (2004). Radiation synthesis of hydrogels to enhance sandy soils water retention and increase plant performance. *Journal of applied polymer science*. **93(3)**, 1360-1371.

Fidelia, N. and Chris B. (2011). Environmentally friendly superabsorbent polymers for water conservation in agricultural lands. *Journal of Soil Science and Environmental Management*. **2(7)**, 206-211.

Hafiz-Afham, K., Hasan N.A., Rafii M.Y. and Sidik N.J. (2023). The growth impact of *Capsicum annuum* crops in hydrogel incorporated media. In *IOP Conference Series, Earth and Environmental Science*. **1155(1)**, 012031.

Hamidi, M., Amir A. and Pedram R. (2009). Hydrogel nanoparticles in drug delivery. *Advanced Drug Delivery Reviews*. **60(15)**, 1638–1649.

Hejazi, M., Santos Da Silva S.R., Miralles-Wilhelm F., Kim S., Kyle P., Liu Y., Vernon C., Delgado A., Edmonds J. and Clarke L. (2023). Impacts of water scarcity on agricultural production and electricity generation in the Middle East and North Africa. *Frontiers in Environmental Science*. **11**, 1-16.

Jnanesha, A.C., Kumar A. and Lal R.K. (2021). Hydrogel application improved growth and yield in Senna (Cassia angustifolia Vahl.). *Industrial Crops and Products*. **174(2)**, 114175.

Kalhapure, A., Kumar R., Singh V.P. and Pandey D.S. (2016). Hydrogels, a boon for increasing agricultural productivity in water-stressed environment. *Current Science*. **111(11)**, 1773-1779.

Kashyap, N., Kumar N. and Kumar M. (2005). Hydrogels for pharmaceutical and biomedical applications. *Critical Reviews in Therapeutuic Drug Carrier Systems*. **22**, 107-149.

Kaur, P., Agrawal R., Pfeffer F.M., Williams R. and Bohidar H.B. (2023). Hydrogels in agriculture, Prospects and challenges. *Journal of Polymers and the Environment*. **31(9)**, 3701-3718.

Koudela, M., Hnilièka F., Svozilová L. and Martinková J. (2011). Cauliflower qualities in two irrigation levels with the using of hydrophilic agent. *Horticultural Science* **38(2)**, 81-85.

Kreye, C., Bouman B.A.M., Castaneda A.R., Lampayan R.M., Faronilo J.E., Lactaoen A.T. and Fernandez L. (2009). Possible causes of yield failure in tropical aerobic rice. *Field Crops Research*. **111(3)**, 197-206.

Kumar, R., Parmar B.S., Kumar A. and Singh M.C. (2005). Performance of a new superabsorbent polymer on seedling and post planting growth and water use pattern of chrysanthemum grown under controlled environment. In *International Conference and Exhibition on Soilless Culture*. **742**, 43-49.

Kumar, R., Nadukeri S., Kolakar S.S., Hanumanthappa M., Shivaprasad M. and Dhananjaya B.N. (2018). Effect of hydrogel on growth, fresh yield and essential oil content of ginger (*Zingiber officinale* Rosc.). *Journal of Pharmacognosy and Phytochemistry*. **SP3**, 482-485.

Narjary, B., Aggarwal P., Kumar S. and Meena M.D. (2013). Significance of hydrogel and its application in agriculture. *Indian Farming*. **62(10)**, 15-17.

Neethu, T.M., Dubey P.K. and Kaswala A.R. (2018). Prospects and applications of hydrogel technology in agriculture. *International Journal of Current Microbiology and Applied Sci*ences. **7(5)**, 3155-3162.

Pazderù, K. and Koudela M. (2013). Influence of hydrogel on germination of lettuce and onion seed at different moisture levels. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*. **61(6)**, 1817-1822.

Prakash, V., Kavitha J.R. and Maheshwari P. (2021). Moisture conservation practice by using hydrogel in agriculture, A review. *Plant Archives*. **21(1)**, 526-528.

Sajjadi, S.G., Tavassoli A. and Dadmehr M. (2021). Effects of hydrogel on drought resistance of medicinal plant roselle (*Hibiscus sabdariffa* L.). *Iranian Journal of Medicinal and Aromatic Plants Research*. **37(4)**, 584-595.

Saul, J.M. and Williams D.F. (2011). Hydrogels in regenerative medicine. In Principles of Regenerative Medicine, Elsevier, London 2nd edition, 637-661.

Singh, A., Sharma P.K., Garg V.K. and Garg G. (2010). Hydrogels, a review. *International Journal of Pharmaceutical Sciences Review and Research*. **4(2)**, 97-105.

Shibayama, M. and Tanaka T. (2005). Phase transition and related phenomena of polymer gels. *Advances in Polymer Science*. **109**, 1-62.

Stamatialis, D.F., Papenburg B.J., Gironés M., Saiful S., Bettahalli S.N., Schmitmeier S. and Wessling M. (2008). Medical applications of membranes, Drug delivery, artificial organs and tissue engineering. *Journal of Membrane Science*. **308(1-2)**, 1-34.

Water in India, situation and prospects, Report by UNICEF 2013.

Tanaka, T. (1978). Collapse of gels and the critical end point. *Physical Review Letters*. **40**, 820-823.

Tanuja, P. and Anitha B. (2022). Hydrogel Technology in Agriculture. *Just Agriculture*. **3(1)**, 1-4.

Vicky, W. (2007). Hydrogels, water-absorbing polymers. *Catalyst*, **18(1)**, 18-21.