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Hydrogel and its effect on soil moisture status and plant growth: A review

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Abstract
More than 60% of net cultivated area of India comes under the dryland condition and more than 30% of the area faces the problem of insufficient rainfall. To overcome this problem, Hydrogel may prove as a convenient and eco-friendly feasible option to achieve the goal of crop productivity under conditions of water scarcity. Hydrogels can absorb and hold rain water and irrigation water and therefore help to reduce deep percolation by using gravitational water as well as capillary water. Application of hydrogel to soil improves growth and yield attributing characters of different field, ornamental and vegetable crops has been reported. It can be directly applied in the soil at the time of sowing of field crops and near the root zone of nursery plantation. For almost all types of crops in relation to soil type and climate of the country, a very low application rate of hydrogel i.e.2.5-5.0 Kg/ha is effective. They are not only used for moisture conservation, but also have enormous potential to maintain physico-chemical properties like bulk density, porosity, temperature, water holding capacity, CEC etc. and biological properties like microbial environment of the soil. Agricultural hydrogels are eco-friendly, because they are naturally degraded over a period of time, without leaving any toxic residue in the soil and plants. Hence use of hydrogel as a soil conditioner will be a productive option for increasing sustainable agricultural production in moisture-stressed environment.

Keywords: Water stress, crop growth, hydrogel, soil conditioner, soil moisture, water productivity

Introduction
Food grain production of India, during 2017-18, was 277.49 million tons. However, by 2025, the farmers need to produce more than 300 million tons, to meet the ever-growing demand for food. Rainfall is erratic and even when overall rains are ‘normal’, distribution of rainfall might be ‘abnormal’ in timing, geographic reach and quantum distribution. Such natural inconsistency affects our agricultural production severely. The tension between crop production and available water supply is already severe, as agriculture currently accounts for more than 70% of all human water withdrawal and up to 95% in some developing countries. However, the real problem is that this tension is poised to intensify. The 2030 Water Resources Group forecasts that water demand will rise 50% by the year 2030. Agriculture will drive nearly half of that additional demand, because global calorie production needs to feed 9.6 billion people by 2050.

Agriculture is both a cause and a victim of water scarcity. The excessive use and degradation of water resources is creating threat to the sustainability of livelihoods dependent on water and agriculture. Inefficient and uncoordinated water use depletes aquifers, contaminates ground water, reduces river flows and degrades wildlife habitats, and it has caused salinization on 20 percent of the global irrigated land area. Achieving the required levels of production from already depleted natural resources requires profound changes in our food and agriculture systems, ensuring global food security, providing economic and social opportunities, and protecting the ecosystem services on which agriculture depend. There is a need for actions and strategies that holistically address the interlinkages between water scarcity, agricultural production, food security and climate change. Extensive research all over the world has led to the discovery of a particular class of Super Absorbent Polymers that can increase water use efficiency and enhance crop productivity. From the few past years, scientists are developing various water-saving technologies to sustain the present food self-sufficiency as well as to meet the demands of future. Hydrogel is one of the most popular materials, in addition to increasing water holding capacity for agricultural applications having also been used to reduce water runoff and increase infiltration rates in field. The efficiency of the technology is highly suited for farmers growing crops under rainfed and limited water availability areas.

Application of hydrogel reduces frequency of irrigation in almost all the crops including cereals, pulses, vegetables and flowers, thus reducing time and money spend on irrigation, labour and water costs. They are mainly used for improving irrigation efficiency; smart delivery materials that can help combat plant pathogens even with lower pesticide dosage, reducing the quantity of soluble NPK fertilizers per crop cycle thus contributes towards the conservation of water and environment. This function is particularly important in dry regions, as the hydrogel will hold soil moisture in water-limited areas and feed the necessary water into the root system of the plant.

Historical view of hydrogel

In the history, the term "hydrogel" wasfirst used in an article published in 1894. However, it was not described as we describe it in present context. It was described as a colloidal gel made with inorganic salts (Lee, Kwon and Park). After that, the first cross-linked network material that is mentioned in literature and has its hydrogel properties, the highwater affinity, was a polyhydroxyethylmethacrylate (*pHEMA*) hydrogel developed much later, in 1960, with the aim of using it in permanent contact applications with human tissues. Hydrogels are the first materials developed for uses inside the patient. Since then in 1970s, the use of hydrogel in biomedical applications began to rise. The aims and goals and the number of materials changed and enlarged constantly over the years. According to Buwalda *et al*. (2014), the history of hydrogels can be divided in three main categories as discussed below:

First generation Hydrogels: The hydrogels of first generation were mainly prepared either by polymerization of water-soluble monomers in the presence of a multifunctional crosslinker or by crosslinking of the hydrophilic polymers.

Second generation hydrogels: During the early 1970s the hydrogel research shifted from relatively simple, water-swollen macromolecular networks to hydrogels capable of responding to a change in environmental conditions such as *pH*, temperature or the concentration of biomolecules. These environmental triggers can be used to evoke specific events, such as gel formation and drug release.

Third generation hydrogels: In third generation hydrogels, various other physical interactions such as stereo complexation, inclusion complex formation, metal–ligand coordination and peptide interactions were exploited as crosslinking methods that enhanced the mechanical, thermal and degradation properties of hydrogels.

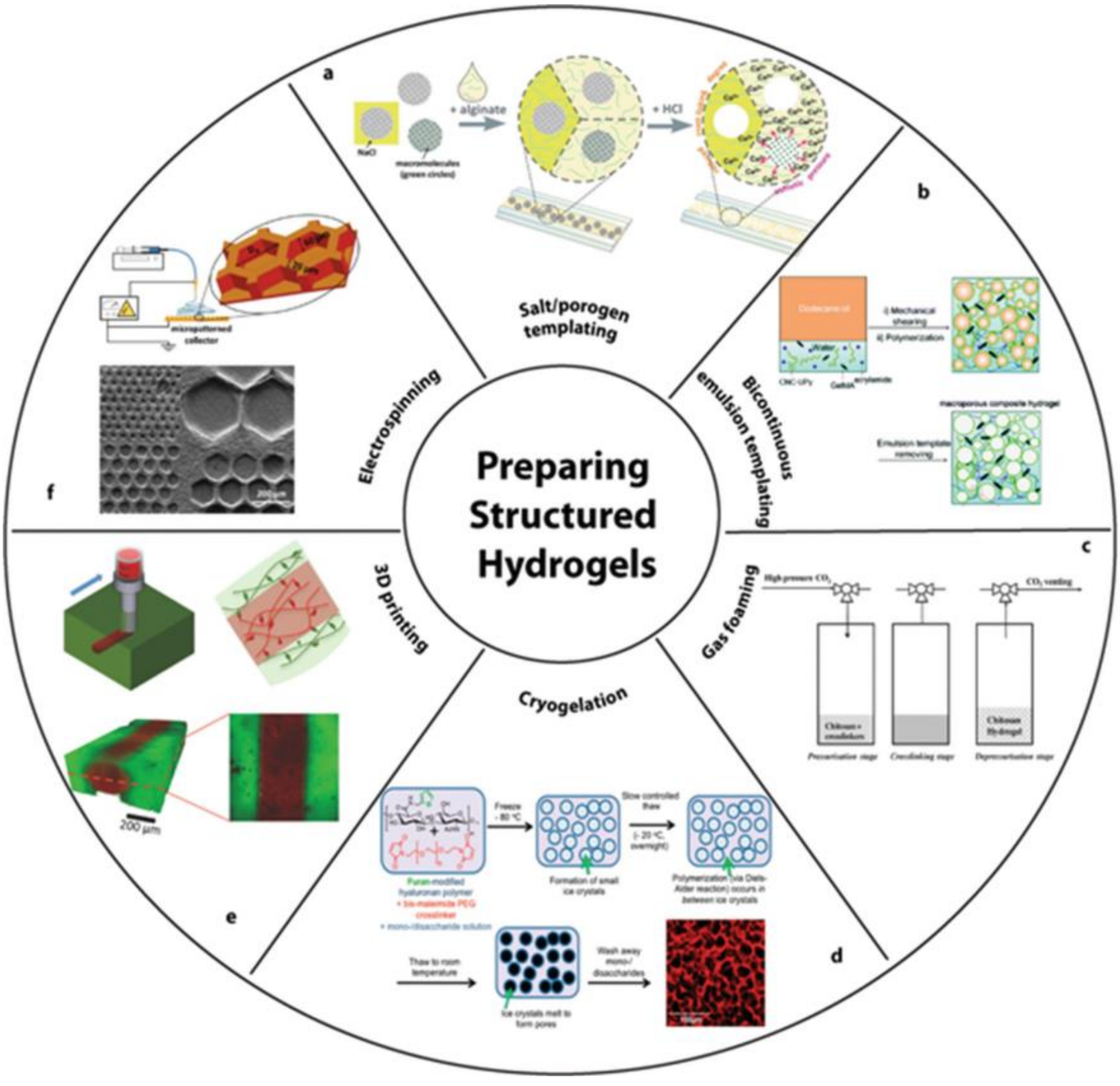

Fig 1: Structuring of third generation hydrogels

Classification of hydrogels

The hydrogel can be classified on different basis as follows:

A) On the basis of source

a) Natural hydrogels
b) Synthetic hydrogels

B) On the basis of polymeric composition

- **a) Homopolymer hydrogels:** Polymer network derivedfrom a single species of monomer, which is a basic structural unit comprising of any polymer network. Cross-linked skeletal structure depends on the nature of the monomer and polymerization technique in such hydrogels.
- **b) Copolymeric hydrogels:** Two or more different monomer species with at least one hydrophilic component, arranged in a random, block or alternating configuration along the chain of the polymer network.
- **c) Multipolymer Interpenetrating polymeric hydrogel (IPN):** Two independent cross-linked synthetic and/or natural polymer component, contained in a network form. In semiIPN hydrogel, one component is a cross-linked polymer and other component is a non-cross-linked polymer.

C) On the basis of configuration

1. Amorphous (non-crystalline)
2. Semi crystalline: A complex mixture of amorphous and crystalline phases.
3. Crystalline

D) On the basis of type of cross linking

1. Chemical cross-link: such cross-linked networks have permanent junctions.
2. Physical cross-link: have transient junctions that arise from either polymer chain entanglements or physical interactions such as ionic interactions, hydrogen bonds, or hydrophobic interactions.

E) On the basis of physical appearance

Hydrogels appear either as matrix or as film, depending on the technique of polymerization in the preparation process.

F) On the basis of charge on cross-linked chain

1. Non-ionic (neutral).
2. Ionic (including anionic or cationic).
3. Amphoteric electrolyte (ampholytic) containing both acidic and basic groups.
4. Zwitter ionic (polybetaines) containing both anionic and cationic groups in each structural repeating unit.

Characteristics of hydrogel

According to Tanaka 1981; Shibayama and Tanaka 1993, hydrogel have the capacity to absorb water and their softness makes hydrogel unique materials. The ability of water absorption of hydrogels arises due to hydrophilic functional groups attached to the polymer backbone while their resistance to dissolution arises due to cross-links between network chains. The features of ideal hydrogel materials are listed as follows:

- They are non-toxic material having no colour and odour.
- They havehigh-water absorption capacity.
- They perform very well even at high temperature therefore suitable for arid and semi-arid conditions.
- Improves the physical condition of soil such as porosity, bulk density, water holding capacity and permeability.
- The lowest soluble content and residual monomer.
- It is a cost-effective material.
- The high durability and stability in the swelling environment and during the storage.
- High biodegradability without formation of toxic species following the degradation.
- pH become neutral after swelling in the water.
- Hydrogel gives desired rate of absorption as per the application requirement.
- Hydrogel is a photo stable material.

- Re-wetting capability: The hydrogel has to be able to give back the imbibed solution or to maintain it; depending on the application requirement.

Hydrogels may absorb water from 10-20% up to thousands of times their dry weight. The character of the water in a hydrogel can determine the overall permeation of nutrients into and cellular products out of the gel. When a dry hydrogel starts absorbing water, the first water molecules entering the matrix will hydrate the polar, hydrophilic groups, leading to primary bound water. As the polar groups are hydrated, the network swells, and hydrophobic groups are exposed, which further interact with water molecules, leading to hydrophobically bound water, or secondary bound water. Primary and secondary bound water are often combined and simply called the total bound water. After the polar and hydrophobic sites have interacted with and bound water molecules, the network will imbibe additional water, due to the osmotic driving force of the network chains towards infinite dilution. This additional swelling is opposed by the covalent or physical crosslink, leading to an elastic network retraction force. Thus, the hydrogel will reach an equilibrium swelling level. The additional swelling water that is imbibed after the ionic, polar and hydrophobic groups become saturated with bound water is called free water or bulk water, and is assumed to fill the space between the network chains, and/or the center of larger pores, macropores or voids. As the network swells, if the network chains or crosslink are degradable, the gel will begin to disintegrate and dissolve, at a rate depending on its composition.

Water absorption with hydrogel

Hydrogels are hydrophilic in nature and contain carboxylic groups, enabling them to bind cations and adsorb water. Many factors affect the absorptive capacity of hydrogels for water which includes the tolerance of hydrogels to ionic solutions, the tensions at which they bind water, and the speed with which they degrade in the field. The availability of water in the soil is vital to various plant kinds and vegetation, the use of hydrogel provided solutions for the shortage in fresh water for agriculture which is to increase soil and water productivity without destroying the environment and the natural resources. Hydrogels have special properties due to their intermediate state between a liquid and a solid. The ability to absorb and to store much water and water solutions make hydrogels unique materials for a variety of applications. Slow releasing polymer hydrogel acts as carriers of nutrients in the soil and considered as a main approach for improving fertilizers efficiency through reducing the nutrient losses by leaching, reducing the cost, and decrease pollution for the environment, hydrogels are very useful in agriculture as they can retain water and avoid soil erosion. El-Ashmar (2017) stated that the application of hydrogel polymer to the soil improving the availability of water in the substrate, enhancement seed germination, increase leaf water content and leaf chlorophyll content under arid region. Improving root development, plant growth, minimize nutrient losses by leaching and contribute to improving soil penetration, decreased the adverse effects of water stress after plant transplantation and implement development of seedling’s parameters.

Drought stress reduction

Drought is one of the major problems in creating stress mainly in the development of plants. The effect of drought stress can effectively be reduced, particularly on seedlings and saplings, the hydrophilic, cross-linked polymers known as super absorbent polymers or hydrogels. Drought stress promotes the production of reactive oxygen species, which can be detrimental to proteins, lipids, carbohydrates, and nucleic acids (Dietz and Pfannschmidt, 2011) [4]. Huttermann *et al.* (1999) [7] reported that the plants have both enzymatic and non-enzymatic defence systems for scavenging and detoxifying ROS. With the ability to absorb more water, hydrogel, during the drought period helps by reducing permanent wilting pointand increasing the available water content in the soil. Hydrogel releases water and nutrient to the plants when surrounding soil around root zone of plants starts to dry up, plant growth is mainly a utility of fertilizer and water for prolonging the survival of plants under drought conditions.

Table 1: General recommended rate of hydrogel

Particulars	Recommended dose of hydrogel
Arid and semi-arid regions	4-6 g/kg soil
For all level of water stress treatment and improved irrigation period	2.30-3.0 g/kg soil
To delay PWP in sandy soils	0.2-0.4 g/kg soil or 0.8% of soil
To improve relative water content and leaf water use efficiency	0.5-2.0 g/pot
To reduce irrigation water by up to 50% in loams	2-4 g/plant pit
To reduce drought stress	0.2-0.4% of soil
To decrease water stress	3% weight basis
To prohibit drought stress totally	250-300 kg/ha

Effect of hydrogel on water holding capacity

Wang and Gregg (1990) [13] stated that the hydrogels absorb many times their weight in deionized or the distilled water. Synthetic hydrogels maintain structural integrity upon hydration and are less damaged by fertilizer salts than starch-based hydrogels.

Bakass *et al*. (2002) [3] reported that the use of hydrogels is particularly useful in arid and semiarid regions where irrigation water is limited. Application of hydrogel @ 2 g/kg soil, improved the water holding capacity of sand from 171% to 402%. Hydrogel decreases the irrigation requirements of several crops by improving water holding capacity.

Akhter *et al.* (2004) [1] reported that the application of hydrogel increased the soil water storage in both sandy loam and loam soils compared with control. The amendment with hydrogel slowed the rate of soil moisture loss that caused a delay in wilting of seedlings grown in both soils. The onset of permanent wilting pointwas delayed by 1.5, 2 and 5 days in sandy loam soil with increase inhydrogel concentration 0.1, 0.2 and 0.3%, respectively. In loam soil, the onset of permanent wilting pointlevel was delayed by 4 days at the three appliedhydrogel concentrations.

Gilbert *et al*. (2014) [6] revealed thatHydrogels had an impact on soil moisture content in the soil after transplanting in arid and semi-arid climate. Analysis of variance shows that; F

0.05(1) = 5.2690 > F critical (4.0662). Hydrogels has a significant difference on the growth of transplanted seedlings in the field. Hydrogels improve soil moisture content in the soil and provide water to theplants during dry season. This was experienced in soils treated with hydrogels gained more soil moisturecontent as compared to controls.

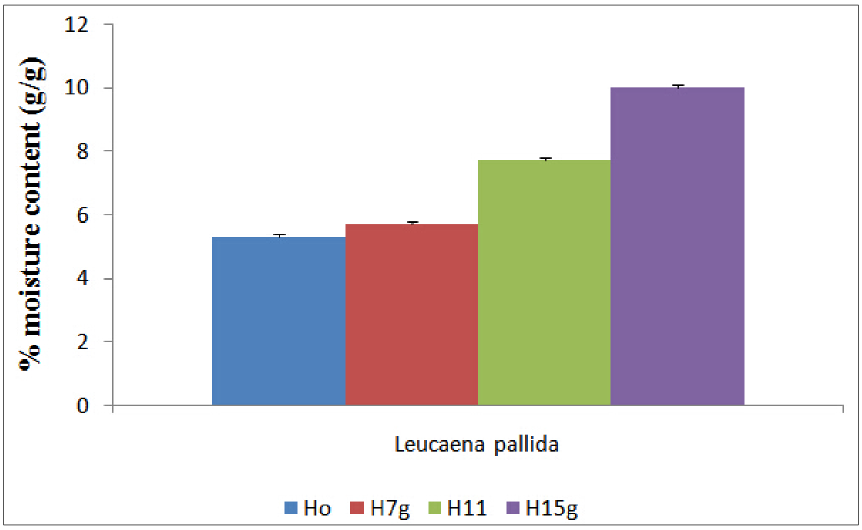

Fig 2: Effects of hydrogels on soil moisture after transplanting

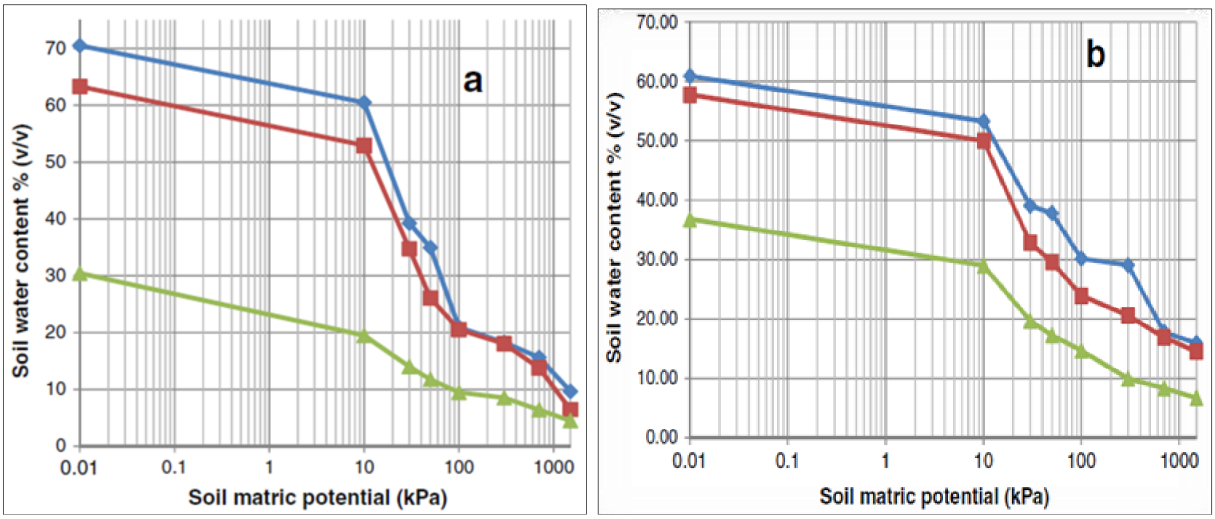

Fig 3: Soil water characteristics curve of (a) sandy and (b) sandy loam soil under different gel application rates [Narjary *et al.,* 2012]

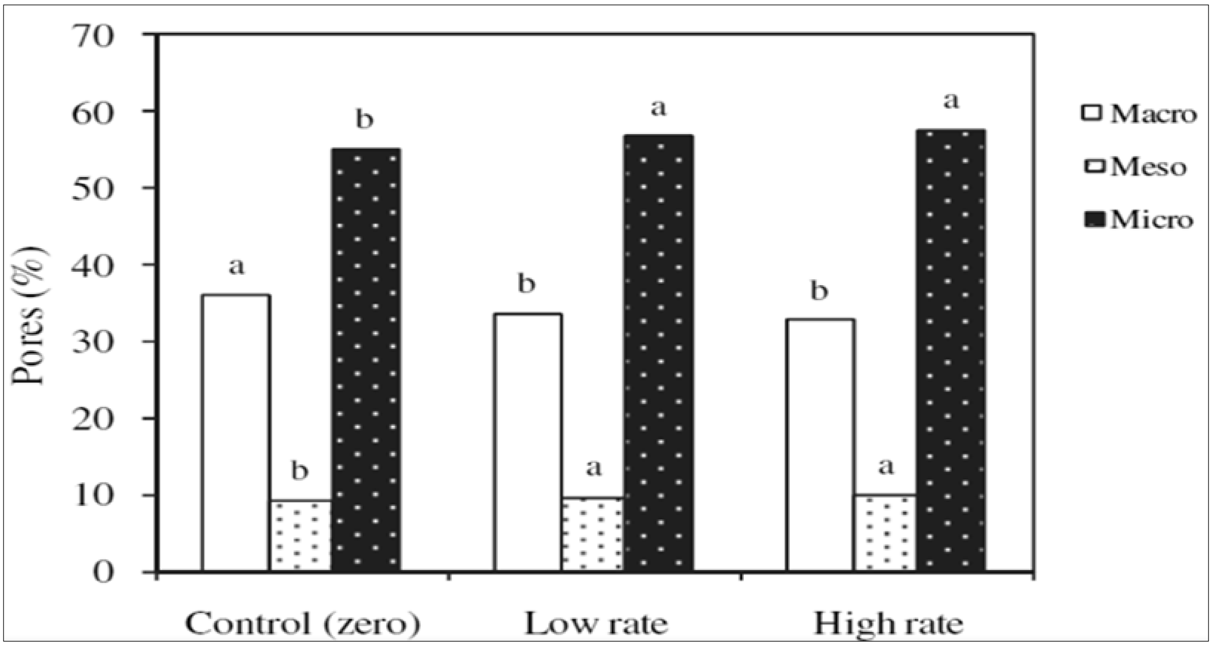

Fig 4: Effect of Hydrogel on soil porosity of sandy loam soil (Asghari *et al*. 2011)

Table 1: Effect of Hydrogel on soil moisture content (%) in different sowing techniques of aerobic rice (0-15 cm) [Rehman *et al.* 2011] [10].

Treatment	21 DAS	35 DAS	77 DAS	84 DAS	Average
No Hydrogel					
Flat Sowing	9.88	10.09	9.59	10.03	10.24
Bed Sowing	10.82	10.18	9.54	10.07	10.35
Hydrogel (2.5 Kg/ha)					
Flat Sowing	12.78	12.21	12.83	13.31	12.67
Bed Sowing	14.11	14.54	14.29	14.82	14.20

Effect of hydrogel on plant growth

Roy *et al.* (2019) stated that the application of hydrogel in Rabi wheat significantly impacted plant population and tillering. The plant population of wheat per m^2 was 210 for hydrogel applied plots while it was only 163 per m^2 for the non-hydrogel applied plots (CD $P < 0.05 = 38.04$). The plant population of wheat increased significantly in hydrogel applied plots. Effective tillering in wheat was evident posthydrogel application. For WH the effective tillers per plant were 7 while for WHO plots it was only 5. Maximum tillering was observed in the hydrogel applied plots with a value of 1541 m^2. For the control plots the effective tillers per m^2 was 850 which was notably less than the hydrogel applied plots,indicating the positive impact of hydrogel application intillering and consequent crop yield. Hydrogel is hydrophilic in nature with the capacity toabsorb huge quantity of water almost 200–400 times its weight. Thus, its application in rhizosphere helps to retain moisture for a longer time period and helps overcome

dry spells. Increased moisture availability in the surface soil layer enhanced germination of wheat and resulted in increased plant population in the present study. There was an increment of 22% in plant population in WH plots compared to WHO. Increased plant population in turn indicates higher tillering and a higher number of effective tillers per unit area. Enhancement in the number of tillersis solely attributed to hydrogel application since all other management practices were uniformly practised by the farmers for both WH and WHO. Significantly higher

tillering in wheat due to hydrogel application at the rate of 2.5 kg ha^{-1} was observed. Rice crop also showed robusttillering due to more moisture retention with hydrogel.

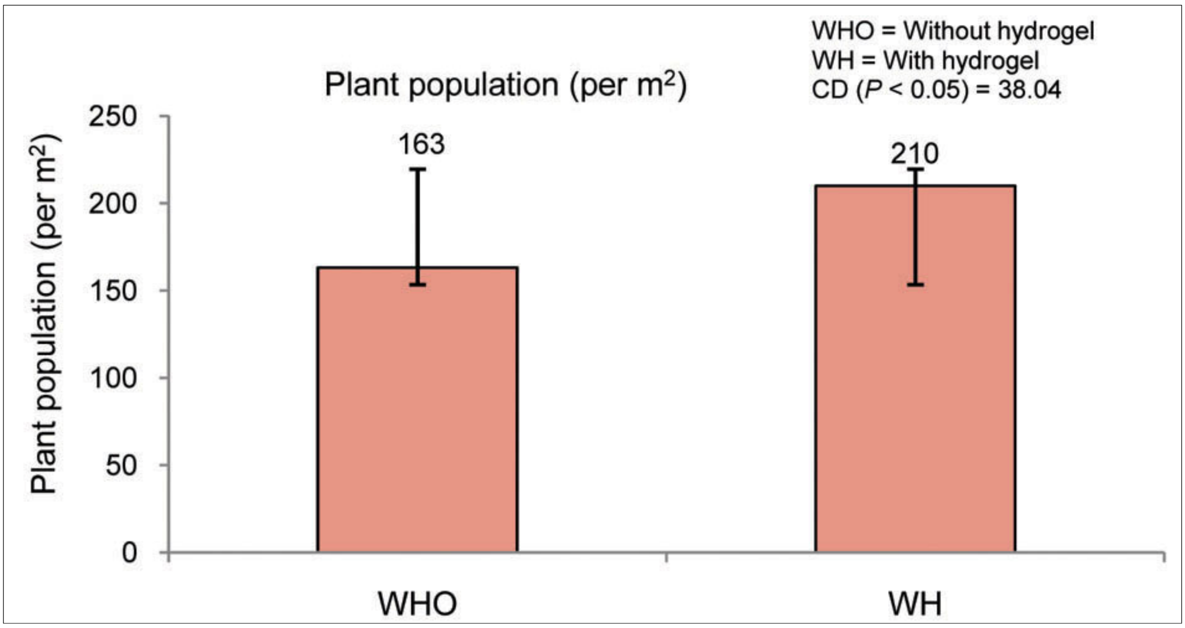

Fig 5(a): Plant population of wheat as affected by application of hydrogel.

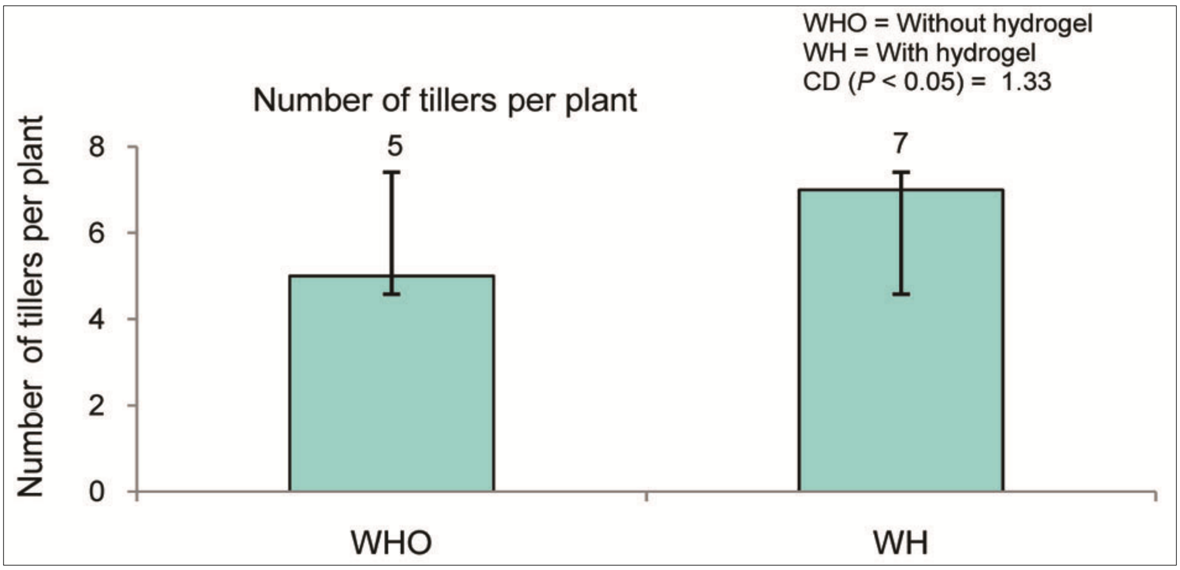

Fig 5(b): Impact of hydrogel on tillering of wheat

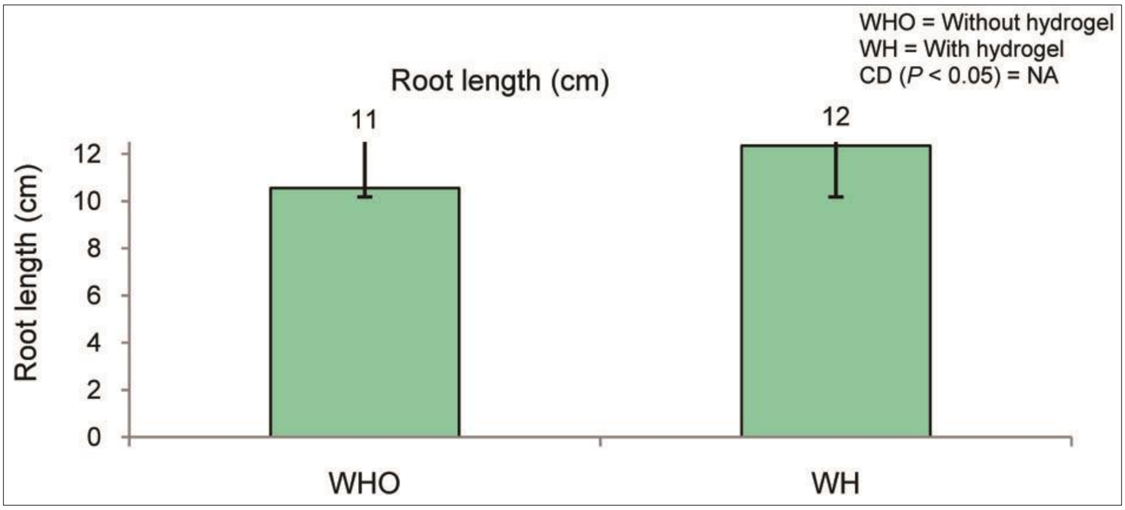

Fig 5(c): Root length as affected by hydrogel application

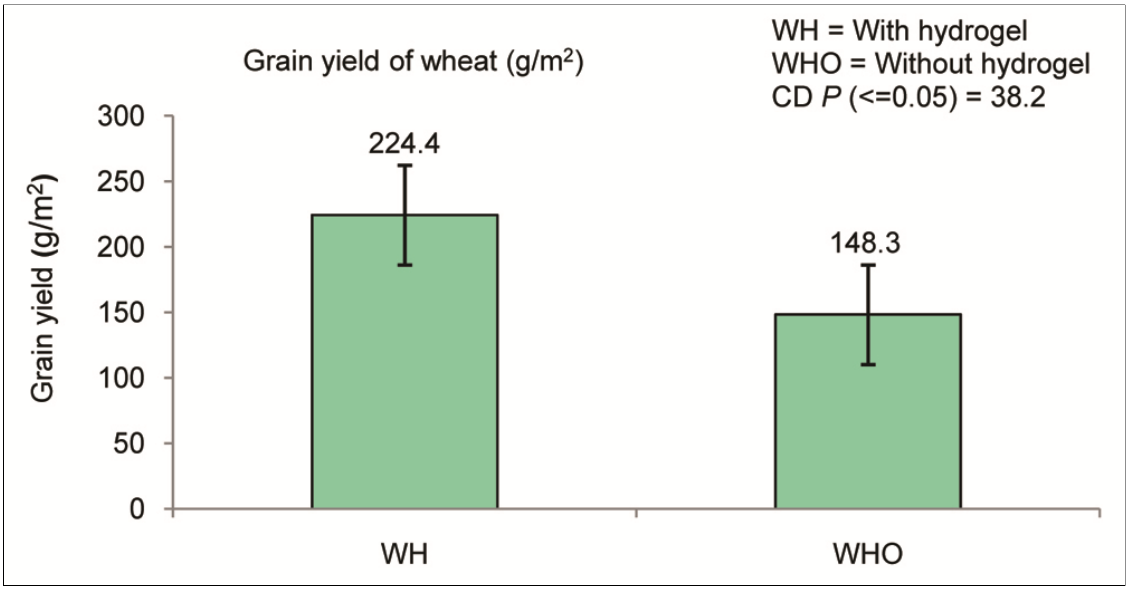

Fig 5(d): Impact of hydrogel application on grain yield of wheat

Conclusion

Hydrogel is basically a water absorbing polymer, classified as cross-linked, absorbing aqueous solution through bonding with water molecules. In agriculture sector there are many uses of hydrogel, due to its water holding capacity. Hydrogels are polymer that can absorb upto 500-600 times their weight and swell to many times to their original size in pure water and form gels. They are therefore used to increase water holding capacity of amended media so as to aid in the establishment and growth of plant crops in dry soil. Hydrogel increased the field water content as the water potential of soil reduced slowly with hydrogel and the effect increased with the increase of hydrogel content under no water supply condition. The relative water content and water potential of leaves decreased slowly and the seedling growth was retarded later with the increase of hydrogel. The Seedlings survival time was prolonged by the application of hydrogel. Therefore, this review envisaged the use of hydrogel on a large scale might have a revolutionary influence on the optimization of water resources management in agriculture.

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