__Review Article__

HYDROGEL IN DRYLANDS: A REVIEW

ABSTRACT

India ranks 41st among 181 countries of the world with regard to moisture stress. More than 60% of the net cultivated area is under dryland condition. Also, more than 30% of the area faces the problem of insufficient rainfall. The problem of optimal capitalization and recovery of water from any source should be seen as a major goal of scientific research as water will become the “cornerstone” of sustainability and the future of humanity. So, there is a strong need for plant growth media with increased water and nutrient holding capacity. Hydrogels retain substantial quantities of both water and nutrients within their three dimensional polymeric network. Hydrogels’ ability to absorb water reduces irrigation frequencies, found to be advantageous for agricultural use. It is efficient as a water-holding reservoir and nutrient mobiliser when used in the soil. Hydrogel application will be a fruitful and benificial option for increasing productivity of various agricultural cropsalong with sustainability in moisture-stressed condition.

Keywords: Agriculture; Dryland; Hydrogel; Irrigation; Polymer

1. INTRODUCTION

Hydrogel (Super absorbent polymer) is a water retaining, cross-linked hydrophilic, biodegradable amorphous polymer which can absorb and retain water at least 400 times of its original weight and make at least 95 per cent of stored water available for crop absorption (Johnson and Veltkamp, 1985).When polymer is mixed with the soil, it forms an amorphous gelatinous mass on hydration and is capable of absorption and desorption over long period of time, hence acts as a slow release source of water in soil. The hydrogel particles may be taken as “miniature water reservoir” in the soil and water will be removed from these reservoirs upon the root demand through osmotic pressure difference. Hydrogels are hydrophilic polymers, with a three-dimensionalnetwork structure that has the ability to absorb a large volume ofwater due to the presence of hydrophilic moieties (Habib *et al.,* 2015).The term hydrogel was first coined by Van n Bemmelen in 1984 (vanBemmelen, 1894).By tuning theirphysicochemical properties and crosslinking reaction, the hydrogel canbe processed as solid, semi-solid and liquid (Varaprasad *et al.,* 2017)

2. CHARACTERISTICS OF SUPERABSORBENT POLYMER- HYDROGEL:

In India, a few research works has been done on the use of polymers in agriculture. Of late, polymers are being introduced in India by many firms with different trade names with an aim to promote them in dryland agriculture for saving water as well as nutrients.The dose of polymers varies from 2.5 to 60 kg ha^{-1} depending upon type of polymer, method of application, type of crop etc. Super absorbents were introduced to the markets in early 1960s by the American Company, Union Carbide. Materials having the capacity to absorb water 20 times more than their weight is considered as superabsorbent (Abedi-Koupal and Sohrab, 2004). But due to development of more cross-linked polymer with high water holding capacity (400 times & even up to 2000 times of their weight) and comparatively low cost has rejuvenated interest on the use of polymer in agriculture. Both water soluble and insoluble polymers have been marketed for agricultural use. Water-soluble polymers do not form gels and are used as soil conditioners. These include polyethylene glycol, polyvinyl alcohol, polyacrylates and polyacrylamides. Water soluble polymers were developed primarily to aggregate and stabilize soils, combat erosion and improve percolation and improve crop yield on drought and structureless soil. Depending on type of polymer and the condition during synthesis, water absorbent polymer has the ability to absorb up to 1,000 times or more of their weight in pure water and form gels. Because of its tremendous water absorbing and gel forming ability, they are referred as super absorbents or hydrogels.There are three main groups of hydrogels (i) Starch- graft co-polymers (ii) Polyacrylates (iii) Acrylamide-acrylate co-polymers.The desertification and lack of water are serious problems in many parts of the world because of compromise agriculture farming. Desertification is the degradation of land in arid, semiarid and dry areas resulting from various factors including climatic variations, but primarily human activities.The solution of this problem is by the use of synthetic materials with good water absorption and retention capacities under high pressure or temperature. Systems of this type are the Super Absorbent Polymers (SAPs). Super absorbent polymer holds 400-1500 g of water per dry gram of hydrogel and makes 95% of their stored water is available for plant absorption.

2.1. HYDROGEL STRUCTURE

The solid form of a hydrogel is a network structure of crosslinkedpolymer chains (Ullah *et al.*, 2015). The molecular weight of the hydrogelleads to infinity because of its 3D network structure (Rosiak *et al.*, 1995).At the molecular level, the most important properties to define thehydrogel structure are the mesh size, and the molecular weight of polymer chain between the crosslinks (Figure 1) (Ganji *et al.*, 2010).The hydrogel is a polymer of a type of substance called a carboxylic acid. The acid groups stick off the main chain of the polymer. When the hydrogel is put into water these acid groups react, the hydrogen atom comes off and the polymer chain is left with several negative charges along its length. (Note: H_3O^+ is another way of writing H^+ in solution and shows that an acid is present.)

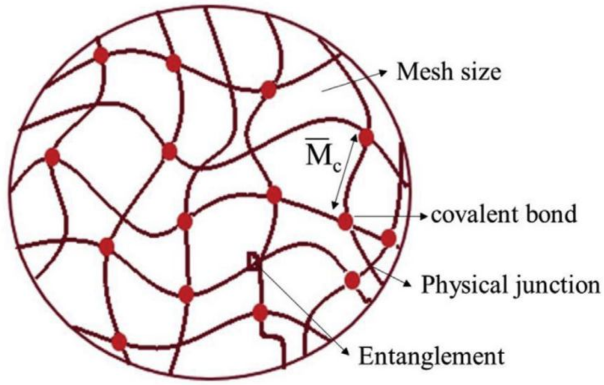

Fig. 1. Structure of hydrogel at molecular level (Aswathy *et al.*, 2020)

3. **SALIENT FEATURES**

1. Exhibits maximum absorbency @ temperatures (40- 50^{0}C) characteristic of semi-arid and arid soils
2. Absorbs water 400 times its dry weight and gradually releases the same
3. Stable in soil for a minimum period of one year
4. Less affected by salts
5. Low rates of soil application – 1-2 kg / ha for nursery horticultural crops; 2.5-5 kg/ ha for field crops
6. Reduces leaching of herbicides and fertilizers
7. Improves physical properties of soils and soil less media
8. Improves seed germination and seedling emergence rate
9. Improves root growth and density
10. Helps plants withstand prolonged moisture stress
11. Reduces nursery establishment period
12. Reduces irrigation and fertigation requirements of crops
13. Promotes early and dense flowering and fruiting/ tillering.
14. Delays onset of permanent wilting point
15. Reduction in nursery establishment period of chrysanthemum (18 days as compared to 28 days in control)
16. Extensive root growth resulting in increased water and nutrient use efficiency

17. Decrease in no. of fertigation booms required to raise nursery and the crop of tomato in field (37 as compared to 52 in control)

18. Significant enhancement in the efficiency of seed germination and seedling growth as compared to control

4. AGRICULTURAL HYDROGELS CAN CHANGE THE PHYSICAL PROPERTIES OF SOILS BY:

1. Increasing their capacity to hold water

2. Reducing erosion and runoff

3. Reduce frequency of irrigation

4. Increase the efficiency of the water being used

5. Increase soil permeability and infiltration

6. Reduce the tendency of the soil to get compacted

7. Help plant performance.

5. DESIRABLE CHARACTERISTICS OF HYDROGEL FOR APPLICATIONS IN AGRICULTURE

1. High absorption capacity in saline and hard water conditions

2. Optimized absorbency under load (AUL)

3. Lowest soluble content and residual monomer

4. Low price

5. High durability and stability in the swelling environment and during storage

6. Gradual biodegradability without formation of toxic species

7. pH□neutrality after swelling in water

8. Photo stability

9. Re□wetting capability

6. ENVIRONMENTAL SAFETY ASPECTS RELATED TO HYDROGEL

1. Inherent toxicity of the unreacted monomer acrylamide, acrylic acid, acrylate etc. present in the finished products.

2. Super absorbent polymers (SAPs) materials cannot return to their starting monomers, i.e. they are scientifically irreversible to toxic initiating materials.

3. Moderately bio-degraded in the soil by the ionic and microbial media to convert finally to ammonia and carbon dioxide.

4. Worldwide research has shown little or no consistent adverse effect on soil microbial populations

5. A very simple and efficient HPLC method to estimate residual monomer content in the hydrogels has been developed in our laboratory

6. It has been confirmed that Pusa Hydrogel does not contain any traceable residual unreacted monomer and is thus environmentally safe.

7. Hydrogels of this type degrade completely into carbon dioxide, water and ammonia within one year.

8. Recommended application rate of Pusa hydrogel is very low i.e. 2.5 kg ha^{-1} for most of the crops which is equivalent to 2.5 ppm per unit weight of the soil.

9. Whereas commercial materials are purely synthetic in nature, Pusa Hydrogel is semi synthetic in nature resulting in reduced load of monomer component in the finished product.

7. **SIGNIFICANCE OF HYDROGEL**

The significant improvement in the quality of agricultural produce in terms of fruit size and colour enhancement in yield (10-50%) and increased plant biomass is reported with the application of hydrogel.Application of super absorbent polymer increases dry yield of flaxseed oil plant, kidney beans, tomatoes and maize.It has also resulted in 30-50% reduction in the frequency of irrigation (thus reducing drudgery in terms of labour involved in frequent irrigation, particularly in vegetable). It 22-30% reduction in the dosage of fertilizers, improvement in hydro- physical environment of soil and high benefit cost ratio.The polymer is releasing fertilizer agent in soil matrix, and decreases ammonium leaching rate. While increasing in water retention in light soils, polymers can address permeability problems in heavy soil and problems in leaching fertilizer.

Super absorbent polymer biodegradation in soil, increases bulk density (or apparent specific weight) soil. As an effective material, super absorbent polymer were identified as effective in reducing the effects of drought stress and thereby increasing plant resistance to stresses and increasing plant performance.Super absorbent polymers cause to increase aggregatestability and prevent crust formation, prevent on farm runoff formation and reduce soil erosion. And the most important benefit of hydrogel usage is preventing deep penetration of water of root environmentand leaching salts and its effect on the accumulation of proline and soluble sugars. Major applications of hydrogelinclude biomedical, dyes removal, heavy metal ions removal, agriculture,sanitary diapers, pH-sensors, biosensors, and supercapacitors (Bahram*et al.*, 2016).

Table I. Agricultural hydrogel products available in India (Kalhapure*et al.*, 2016)

Trade name	Manufacturing company
Pusa Hydrogel	IARI, New Delhi
Waterlock 93N	Acuro Organics Ltd, New Delhi
Agro-forestry water absorbent polymer	Technocare Products, Ahmedabad
Super absorbent polymer	Gel frost packs, Kalyani enterprises, Chennai
Hydrogel	Chetex Speciality Ltd, Mumbai
Rain drops	M5 Exotic Lifestyle Concepts, Chennai

8. EFFECT OF HYDROGEL ON WATER USE EFFICIENCY

Common super absorbent polymers are generally white sugar like hygroscopic materials can be used for improving irrigation efficiency. Use of water soluble polymers 0.75% w/w with 50% attainable moisture depletion to tomato in sandy loam soil produced the maximum water use efficiency (153.6 kg m^{-3}) as compared to other levels of polymer application (0, 0.25, 1.25 and 1.75%). Application of carboxymethyl cellulose at 2% and 4% dose with compost @ 5 tonnes ha-1 resulted in increase of maize yield by 25 and 34%, respectively over the untreated sandy soil. The combined effect of both soil conditioners on water use efficiency was better than that of their sole application.

8.1. EFFECT OF HYDROGEL ON ROOT ACTIVITIES

With an increase in concentration of hydrophilic polymer, significantly increased the root parameters like root length, root volume, root fresh and dry weight at harvest in tomato due to proper maintenance of water by hydrophilic polymer for longer duration. Volkamar and Chang (1995) reported that hydrophilic polymer @ 1.87 g plant-1 increased root biomass as compared to control. Similarly, Sendur*et al.* (2001) concluded that hydrophilic polymers significantly increased root length as well as root dry weight as compared to control which was in accordance with findings of Taylor and Halfacre (1986).

A field experiment was carried out C6 block at Bihar Agricultural College Farm, Sabour, Bhagalpur during rabi season 2011-12 by Rohit kumar and their co-worker, to study the effect of hydrogel on growth and yield of maize well as on soil properties, water productivity and the economics of applying hydrogel in maize. The experiment was conducted in split plot design, replicated thrice.The treatments comprised of two main plot treatments i.e. two sources of hydrogel, Stockosorb and Pusa gel and six sub-plot treatments having doses of hydrogel i.e. control, 50, 75, 100, 125 and 150 % recommended dose of hydrogel. The conclusion of the study are:

1. The sources of hydrogel viz., stokosorb and pusa gel did not have any significant impact on growth and yield of crops, economics of production, physical soil properties and water productivity of crops of rabi maize.

3. Grain yield of maize was produced maximum at 150 % recommended dose of hydrogel.

4. Highest net return was fetched by application of 75 % recommended dose of hydrogel.

5. Highest water productivity (water use efficiency) was obtained when 150 % of recommended dose of hydrogel was applied.

6. Soil physical properties in terms of bulk density, porosity and water holding capacity was improved by the use of hydrogel and 125 % dose of hydrogel was found to be the best.

9. BIODEGRADABLE NANO-HYDROGELS IN AGRICULTURAL FARMING

Nanotechnology is the modern technology used in agriculture. The yield of crop production in dry land areas is mainly influenced by variation in amount and distribution of rainfall. 70 percent of 143 million hectare of total cultivated area in the country is rainfed. The dry land areas supplies 42 percent of the total food grain production of the country.The most critical factor of failure in yielding the second crop after the rice production is soil moisture. According to the report of Hayat and Ali (2004), the restrictive factor for crop production in arid and semi-arid regions is Moisture Stress due to low and uncertain. The Silver coated nano-clay composite cross-linked polyacrylamides polymers were developed in the Department of Biotechnology, Acharya Nagarjuna University, Nagarjunanagar and Guru Nanak Institute of Technology, Ibrahimpatnam R.R. Dist, Telangana during 2009-14.

Silver coated hydrogels were synthesized by polymerization reaction with 8% acrylic acid, 1-5% acrylamide, 0.9% ammonium persulphate as initiator, 0.12% N, N-methyl biscrylate as cross linker loaded with 10% clay at 65ºC reaction temperature in presence of nitrogen gas. Before polymerization reaction 10% of Silver nitrate was added for the formation of Silver–coated SAP. The dried polymerized sample was further crushed in a heavy wooden mortar and made into a fine powder. This product was tested for water sorption properties for agriculture purpose.

9.1. **Modification of Hydrogel**

Nanostructured clay is used in three forms: as a powder, aqueous suspension and in jelly-consistence. Silver nitrate is added to the water at 65°C under stirring, subsequently the clay is added and finally, after perfect homogenization, 1 g of dry hydrogel is added.It is allowed to stand for 10 minutes to produce solid SAP and filtered by using a Buchner funnel.The filter cake is transferred to a china dish for drying.

9.2. **Determination of Degree of Swelling:**

250 mg of prepared Super Absorbent Polymer is transferred to a glass beaker containing 250 to 300 ml of distilled water or 50 ml of 0.9 wt% NaCl solution and allowed to stand to examine the degree of swelling of the polymer. After the polymer attains the equilibrium-swelling state, it is filtered with the help of 30µm filter cloth or a paper filter and is weighed.The degree of swelling is then calculated from the ratio of weighed-out sample to weighed-in sample in g/g. Each determination is carried out three times with ±5% of

accuracy. The rate of swelling depends on the concentration of polymer and the crosslinking density (Okay, 2010).

Ramesh Vundavallia*et al*., indicated that the water-holding ratio of the soil with silver coated hydrogel and soil with hydrogel was 7.5% and 3.5% higher respectively, when compared to original soil.This shows that the silver coated hydrogel has excellent water absorbency in soil, and improves the water holding capacity and water use efficiency of the soil. The silver coated hydrogels resourcefully store rainwater or irrigation water to 130 to 190 times of its weight. This is one of the significant advantages over the conventional coated slow-release fertilizers.

10. **CONCLUSION:**

Hydrogel application in almost all the test crops (cereals, vegetables, oilseeds, flowers, spices etc) has resulted in significant improvement in the quality of agricultural produce in terms of fruit size and colour, enhancement in yield and increased plant biomass. It has also resulted in reduction in the frequency of irrigation, reduction in the dosage of fertilizers and improvement in hydrophysical environment of soil and high benefit cost ratio. Hydrogel reduces the frequency of watering by up to 70% , thus saving water and your time, hydrogel reduces nutrient leaching to groundwater, and keeps them where they are needed, thus directly at the roots in water solution. This also saves the cost of fertilizer and irrigation. Agricultural hydrogels are not only used for water saving in irrigation, but they also have tremendous potential to improve physico-chemical and biological properties of the soil. Hence application of hydrogel will be a fruitful option for increasing agricultural production with sustainability in moisture-stressed environment.

REFERENCES:

Abedi-Koupai, J and Sohrab, F. Effect of super absorbent application on water retention capacity and water potential in three soil textures. Journal of Science and Technology of Polymers. 2004; 17 (3): 163-173

Allahdady. Examining application effects of super absorbent hydrogels on reducing drought stress in plants. Second specialized course, learning agricultural and industrial applications of super absorbent hydrogels, Iran polymer research institute of petrochemical. Pakistan journal of biological sciences. 2002;10(23): 4190-4196.

Asgari FN, Omidian H and Hashemi V. Syntetic Reorganization and Modification the Properties of Superabsorbent Polymers. Journal of applied Polymer Sciences. 1994; 2(54):241 – 249.

Aswathy SH, Narendrakumar, U and Manjubala I. 2020. Commercial hydrogels forbiomedical applications. Heliyon 6(4).

Bahram M, Mohseni, N andMoghtaderM, An introduction to hydrogels and somerecent applications. In Intech Open. 2016.

Choudhary. Pop. Kheti. 2014; 2(4):154-158.

Ganji F, Vasheghani-Farahani S and Vasheghani-Farahani E. Theoreticaldescription of hydrogel swelling: a review. Iranian Polymer Journal. (Engl. Ed.). 2010;19 (5):375–398.

Habib MA, Akter MA, Alam ME, Karim Z and Joarder MTA. Hydrogel: a nobleapproach to healthcare. International Journal ofInnovativePharmaceuticalScience and Research. 2015; 3(72). 1372–1388.

Hayat, R., & Ali, S. (2004). Potential of summer legumes to fix nitrogen and benefit wheat crop under rainfed condition. *Journal of Agronomy*.

Johnson, M. S., & Veltkamp, C. J. (1985). Structure and functioning of water□storing agricultural polyacrylamides. *Journal of the Science of Food and Agriculture*, *36*(9), 789-793.

Kabiri.Introduction and Application of Super Absorbent Hydrogels, the Third Training Course and Seminar on Agricultural Applications of Superabsorbent Hydrogels. Iran Polymer and Petrochemical Institute. Iranian Polymer Journal. 2015; 17(6): 451-477.

KalhapureA, Kumar R, Singh VP and Pandey DS. Hydrogels: A boon for increasing agriculturalproductivity in water-stressed environment. Current science. 2016; 111(11).

Okay, O. General properties of hydrogels. Hydrogel Sensors Actuators. 2010; 6: 1–15.

Rohith Kumar, 2015. Evaluation of hydrogel on the performance of rabi maize (*Zea mays* L.). M.Sc. thesis submitted to the Department of Agronomy, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India.

Ramesh Vundavallil, Procedia Materials Science. 2015; 10: 548 – 554

Rosiak, JM. Ulanski, P andRzeznicki, A. Hydrogels for biomedical purposes. Nuclear Instruments and Methods in Physics Research - section B 1995;105 (1–4): 335–339.

Shibayama M and Tanaka T. . Phase transition and related phenomena of polymer gels. Advances in Polymer Science.1993; 109: 1-62.

Sendur, Kumaran, S, Natarajan, S, Muthvel, I and Sathiayamurthy, VA. Efficacy of graded doses of polymers on processing quality of tomato. Journal of Madras Agriculture.2001; 88 (4-6): 298-299.

Tanaka T. Collapse of gels and the critical end point. Physical Review Letters.1978; 40:820–823.

Taylor KC and HalfacreRG. The effect of hydrophilic polymer on media water retention and nutrient availability to*Ligustrum lucidum*. Horticultural science., 1986;21: 1159–1161.

Ullah F, Bisyrul M, Javed F and Akil H. Classification, processing and applicationof hydrogels: A review. Materials Science andEngineering-C. 2015; 57:414–433.

Volkamar KM and Chang C. Influence of hydrophilic gel polymers on water relations, growth and yield of barley and canola. Canadian Journal of Plant Science. 1995;.75: 605-611

Van Bemmelen JM. The hydrogel and the crystalline hydrate of copper oxide.Z. Anorg. Chem. 1894; 5(1): 466–483.

Varaprasad K, Malegowd G, Jayaramudu T, Mohan M and Sadiku R. . A minireview on hydrogels classification and recent developments in miscellaneousapplications. Materials Science andEngineering-C.2017; 79: 958–971.