Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 6[10] September 2017 : 129-135

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.876
Universal Impact Factor 0.9804
NAAS Rating 4.95

REVIEW ARTICLE **OPEN ACCESS**

Hydrogel: To Enhance Crop Productivity Per Unit Available Water Under Moisture Stress Agriculture

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ABSTRACT

India ranks 41st among 181 countries of the world with regard to water 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. Hydrogel (Super absorbent polymer) is a water retaining, 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. When it is mixed with the soil, it forms an amorphous gelatinous mass on hydration and is capable for retaining it for longer period in soil and releasing water slowly as per crop root demand. The improvement in growth and yield attributing characters and yield of different field, ornamental and vegetable crops has been reported with the application of hydrogel. 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 water-stressed environment.
Key words: *water, hydrogel, dryland,crop attributes, yield and water use efficiency*

INTRODUCTION

Water is life because plants and animals cannot live without water. Water is needed to ensure food security, feed livestock, take up industrial production and to conserve the biodiversity and environment. Although, India is not a water poor country, due to growing human population, severe neglect and over-exploitation of this resource, water is becoming a scarce commodity. While this is a growing concern all over the world, India is most vulnerable because of the growing demand and in-disciplined lifestyle. This calls for immediate attention by the stakeholders to make sustainable use of the available water resources to ensure better quality of lives. In India rainfed agro-ecologies contribute 60% of the net sown area, 100% of the forest and 66%of the livestock. About 84–87% of pulses and minor millets, 80% of horticulture, 77% of oilseeds, 66% of cotton and 50% of cereals are cultivated under this region[1]. The area under dryland condition is 85 m ha (60% of total cultivated area), which receives average annual rainfall less than 1150 mm. Also, more than 30% of total geographical area of the country comes under low rainfall (less than 750 mm). India accounts for 2.45% of land area and 4% of water resources of the world, but it has 16% of the world's population. Total utilizable water resource in the country has been estimated to be about 1123 BCM (690 BCM from the surface and 433 BCM from groundwater), which is just 28% of the water derived from precipitation. About 85% (688 BCM) of water usage is being diverted for irrigation in agri culture; it may increase to 1072 BCM by the year 2050[2]. By 2025 (Table 1), demand for domestic and industrial water usage may increase to 29.2 BCM. Thus water availability for irrigation is expected to reduce to 162.3 BCM. A per capita availability of less than 1700 m3 is termed as a water-stressed condition while per capita availability below 1000 m3 is termed as a water scarcity condition.

Table 1: Per capita water availability in India[3].

Year	Per capita water availability (m^3/year)
1951	5177
1955	4732
1991	2209
2001	1820
2025	1341
2025	1140

So, there is a strong need for plant growth media with increased water holding capacity and from past few years researchers are developing water-saving technologies to sustain present food self-sufficiency and to meet future food requirements. Hydrogel (super absorbents) is one of the most popular, having also been used to reduce water runoff and increase infiltration rates in field agriculture, in addition to increasing water holding capacity for agricultural applications. The use of hydrophilic polymers, to improve soil water retention properties and thus, crop productivity is attracting considerable interest. Hydrogel absorbs water after rain or applied irrigation from soil and water which it releases back to the soil as and when the plant demands it. This function is particularly important during dry seasons as the hydrogel will hold soil moisture in water limited areas and feed the necessary water into the root system of the plant. 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. Super absorbents were introduced to the markets in early 1960's by the American Company, Union Carbide4. Materials having the capacity to absorb water 20 times more than their weight is considered as superabsorbent[5]. 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 structure less 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. Polyethylene oxide hydrogel, polyacrylamide hydrogel and cross-linked polyethylene oxide co-polyurethane hydrogel were attempted to alleviate the plant damage that resulted from salt induced and water deficient stress[6]. The determination of amount of gel for the best performance is influenced by many factors including climate, substance type, soil type, crop species etc. Systematic field studies under arid and semi-arid conditions of India are needed to develop appropriate dose, frequency and method of application of different polymers to various crops and to assess economics of use of different polymers.

Working of hydrogel

Hydrogels are characterized by negative (anionic), positive (cationic) or neutral charge. These charge classes are found in both linear and cross-linked polyacryamide hydrogels. The charge determines how they will react with soils and solutes. Briefly, clay components of soil have a negative charge; heavy metals have a positive charge, and other commonly found minerals in soil and water possess either a positive or a negative charge. Therefore, cationic hydrogels generally bind to clay components and act as flocculants, anionic hydrogel cannot directly bind to clay and may act as dispersants. However, anionic hydrogel can bind to clay and other negatively charged particles in the presence of ionic bridges, such as calcium (Ca^{+2}) and magnesium (Mg^{+2}). However, in any given situation hydrogels will act in which manner is hard to predict, as the chemical interactions, and dissolved substances are complex and occur simultaneously. Electrical charges, hydration levels, van der Waals forces, and hydrogen bonding all modify the affinity of the gel for other compounds. The polyacrylamide polymer contains a complex array of positively charged, negatively charged and neutral chain segments, all with varying affinities for other molecules. The stronger the attraction between the gel and surrounding solutes and the soil particles, the greater the ability of the gel to absorb water, create aggregates, and stabilize soil structure.

Key characteristics of agricultural hydrogels

Agricultural hydrogels are natural polymers containing a cellulose backbone. They can also perform well at high temperatures (40–50 ^{0}C) and hence are suitable for semi-arid and arid regions. They can absorb a minimum of 400 times of their dry weight of pure water and gradually release it according to the needs of the crop plant. Hydrogels are found to improve the physical properties of soils (viz. porosity, bulk density, water holding capacity, soil permeability, infiltration rate, etc.). Increase in porosity results in improvement in seed germination and rate of seedling emergence, root growth and density, and reduced soil erosion due to reduction in soil compaction. It also increases biological/microbial activities in the soil, which increase oxygen/air availability in root zone of the plant. Hydrogels help plants with- stand extended moisture stress by delaying the onset of permanent wilting point and reducing irrigation requirements of crops due to reduced water loss through evapo- ration. The water held in root zone of the crop and leaching of nutrients in the soil are also reduced. Agricultural hydrogel can be used for all crops and all soil types. Its benefits are most easily noticed in nurseries and seedling beds, crops sensitive to moisture stress, crops requiring large quantities of water, and container gardens pot cultures.

Application and availability

Available in dry powder the gel should be mixed with approximately 10 times the quantity of the farm soil and basal dose of fertilizers. Seeds to be sown are also mixed with it. The mixture is then applied uniformly in the rows with the help of plough or seed drill. Care must be taken to ensure precision application of the product around or below the seed. Agricultural hydrogel can be used for all crops and all soil types. Its benefits are most easily noticed in nurseries and seedling beds, crops sensitive to moisture stress, crops requiring large quantities of water , and container gardens–pot cultures. Rate of application of agricultural hydrogel depends upon the texture of soil–for clay soil: 2.5 kg/ha (at the soil depth of 6–8 inches). For sandy soil: up to 5.0 kg/ha (at the soil depth of 4 inches).

For field crops: Prepare mixture of hydrogel and fine dry soil in 1 : 10 ratio and apply along with the seeds/fertilizers or in the opened furrows before sowing. For best results, hydrogel should be close to seeds.

- In nursery bed for transplants: Apply 2 g/m^2 (or according to recommended rate) of nursery bed mix of hydrogel uniformly in the top 2 inches of the nursery bed. In pot culture, mix 3–5 g/kg of soil before planting.
- While transplanting: Thoroughly mix 2 g (or according to recommended rate) of hydrogel per litre of water to prepare a free-flowing solution; allow it to settle for half an hour. Dip the roots of the plant in the solution and then transplant in the field.

Effect Of Hydrogel On Growth Parameters Of Crops

Application of superabsorbent polymer could conserve water thereby increasing the soil's capacity for water storage, ensuring more available water, relative water content in leaves and plant growth increased under water stress[7]. Polymer improved seedling growth and increased absorption of nitrogen and nitrogen wasted through leaching of saline soils was reduced[8]. The influence of superabsorbent polymer and water stress on the qualitative and quantitative performance of soybean seed protein was found most significant[9]. Hydrophilic polymer significantly reduced the number of irrigation frequency in tomato by increasing water holding capacity of soil which is in accordance with the results observed in Cupressus[10]. Leaf area indicates good idea of the photosynthetic capacity of the plant and decreased leaf area is an early response to water deficit. With an increase in hydrophilic polymer, there was significant increase in leaf area. Hydrophilic polymer increases the turgor pressure inside the cells by maintaining sufficient amount of water as per crop requirement and thus causing increase in leaf area and other related growth parameters[11]. The amended soil with natural and synthetic polymers improved maize yields by 36%, and 31% and improved dry matter yields by 92% and 81% respectively, than those of the control[12].

Incorporation of hydrogel into the potting medium aided the emergence (20.4 seedling/pot) and survivorship (80-100%) of crested wheat grass seedlings as compared to control with 13.0 seedlings/pot emergence. They also reported that the beneficial effects were greater when watering frequency was lowest and soil texture was sandier [13]. Grain yield of soybean by hydrogel application in drought prone soils and the yield obtained was 1.77, 3.47, 4.98 and 6.41 q ha^{-1} with application of super absorbent polymer@ 0, 75, 150 and 225 kg ha^{-1} respectively [14]. Application of water absorbents results in significantly higher emergence count (180 m^{-2}), plant height (79 cm), effective tillers (264 m^{-2}), grains per panicle (69) grain yield (23.3 q ha^{-1}) of aerobic rice as compared to control [15]. Soil incorporation of hydrogel (1 g plant^{-1}) with 2 kg compost also increased dry weight of tomato as compared to soil treated with 2g hydrogel (43.7 g plant-1) or 2 kg compost (35.0 g plant^{-1}) separately or control (19.2 g plant^{-1}).

The beneficial effects of mixtures of organic matter and hydrogel exceeds that of each conditioner when solely added [16]. Coating of pearl millet seed with 10 and 20 g of hydrogel/ kg of seed resulted in the production of significantly higher effective tillers, ear length, test weight, grain and stover yield compared to control and water soaking treatment [17]. Results of application of 200 kg/ha of hydrogel in peanut were found to be significantly superior in respect of all the growth and yield characters (viz. seed yield, biomass yield, pod yield, number of branches per plant and 100 seed weight) in sandy soil of Iran with hot and arid climate [18].

Effect of Hydrogel On Yield And Yield Attributes

Maize yield increased slightly following superabsorbent polymer application by 11.2% under low and 18.8% under medium dose, but significantly at high and very high doses by 29.2 and 27.8% with only half amount (150 kg ha^{-1}) of fertilizer as compared to control, which received conventional standard fertilizer dose (300 kg ha^{-1}) [19]. Optimum dose of superabsorbent polymer for maizecultivation would be 30 kg ha-1 as it best increased the grain yield. Application of superabsorbent polymer @ 15 kg ha-1 plus only half the amount of conventional fertilizer dose @ 150 kg ha-1would be more appropriate practice for sustainablemaize production under arid and semiarid conditions of northern China. The incorporation of SAP into soil improved crop yield[20]. Yield of wheat was found to increase by 8.48% ove r control with the application of 5 kg/ha of hydrogel in clay loam soil with 100% recommended dose of fertilizers [21]. The results obtained from farmers field demonstration conducted by ICAR at different locations in Uttar Pradesh evidenced that soil application of hydrogel @ 5 kg/ha along with three irrigations in different wheat varieties is able to produce grain yield equivalent to irrigating wheat crop with five times without hydrogel application (Table 4). It indicates that soil application of hydrogel can save two irrigations in wheat without reducing the grain yield. Application of 65% cow manure and 35% superabsorbent polymer (26 tha^{-1} cow manure + 70 kg ha^{-1} super absorbent polymer) increased grain yield by 16.2% as compared to control [22]. An increase in yield and yield related attributes could be because of sufficient availability of water and indirectly nutrients supplied by the SAP to the plants under water stress condition, which in turn lead to better translocation of water, nutrients and photosynthates and finally better plant stand yield [23].

Table 2: Demonstrations in farmers' fields conducted by ICAR in collaboration with ITC group of companies [24]

Zone	No.of villages	Three irrigations without hydrogel	Five irrigations without hydrogel	Three irrigations with 5 kg/ha hydrogel	LSD 5%
Hathras, UP	5	3.65	4.20	4.30	0.28
Hardoi, UP	2	3.75	4.38	4.62	0.33
Gonda,UP	2	3.95	4.80	4.65	0.39
Lucknow,UP	1	4.05	4.75	4.70	0.22

Effect of Hydrogel on Soil Water Content and Water Use Efficiency

Application of superabsorbent polymer could be an effective management practice for maize cultivation in soils characterized by low water holding capacity where rain or irrigation water and fertilizer often leach below the root zone within a short period of time leading to poor water use efficiency by crop [25]. The hydrogel amended soils require less frequent irrigations for crop production, especially early in plant establishment. Further, the hydrogels seemed to increase root growth and decrease irrigation frequency initially for some plants [26]. The application of high levels of Superab A200 addition @ 2, 4, 6 and 8g/kg enhanced available water content approximately 1.8, 2.2 and 3.2 fold in sandy loam, loamy and clay soils respectively as compared to that of the control and there were marked responses in the number of days to permanent wilting point as a result of polymer application. They also reported that the increase in saturated water content in proportion to hydrophilic polymer application, the maximum value of saturated water content was related to 6 g/kg. They concluded that the application of 4 g/kg soil of Superab A200 had a proper performance for Arizona cypress (*Cupressus arizonica*), reduced the required water at least 1/3 of the control. So, application of hydrogel increased the soil water content during growth period and reduced the irrigation requirement. Super absorbent polymers @ 0.5% showed significant results on Sweet Pepper (*Capsicum annum* L.) and the plant height (29 cm), leaf area (22 cm^2), chlorophyll content (1.74 mg/g fresh weight) and yield (171 g/plant) were significantly higher as compared to control [27]. Hydrogels increase the water holding capacity for agricultural applications. they further reported that application of 0.6% hydrogel concentration prolonged the time of water loss from the soil by about 66% and the seedlings grown in 0.6% hydrogel mixed soil survived three times as long as those grown in the control soil, however, was statistically at par with 0.4 % hydrogel concentration[28]. Hydrogels applied to sandy loam soils increased the amount of available moisture in the root zone and water holding capacity resulting in longer intervals between irrigations. The water holding capacity (33.75, 27.10, 23.05 and 20.15%) and available moisture (12.47, 10.62, 7.70 and 4.82 %) were recorded when hydrogel was applied @ 4, 3, 2 and 0 g hydrogel/plant pit respectively. They also reported that application of hydrogel at 2.5 kg ha-1 improved the soil moisture contents of soil and the moisture recorded were 12.78, 13.20, 12.21, 12.87, 11.03, 13.10, 12.83 and 13.31% as compared to control 9.88, 11.15, 10.09, 10.30, 10.45, 10.44, 9.59 and 10.03% at 21, 28, 35, 42, 53, 60, 77 and 84 days after sowing respectively[29]. An experiment in PVC columns in a laboratory at the IARI (New Delhi) on four different soils: red sandy loam, sandy soil, black clay soil and alluvial sandy loam and the results showed that the hydrogel was unsuitable for black soils and hydrogel @ 0.7% was found most suitable that 0.5% hydrogel for growing crops on other soils because the water available to plants grown in gel-treated soils increased by 1.5-2 times over the water available to plants grown in non- gel treated soils[30]. From an experiment at Czech Republic, the influence of hydrogel (water solution 1, 3, 5 g/l) on lettuce and onion seed germination was tested in different moisture conditions and the results showed that hydrogel treated lettuce seeds germinated faster than non-treated control in the beginning of germination process[31]. The hydrogel at 7% concentration was able to reduce the destructive effect of water deficiency, by absorbing and preserving water and improving several agronomic characters and recorded increased yield and its components and decreasing plant water requirement in six oilseed rape genotypes[32]. Hydrogel application in irrigation withholding at different growth stages had positive effect on all attributes except for protein percentage in wheat crop and further reported that with attention to increased yield and its components and decreasing plant water need, using this material is economically acceptable[33]. Consumptive use of water increased with the increase in irrigation levels (Table 3), while increase in hydrogel level decreased the consumptive use of water. With 3 irrigations by using 2.5 or 5.0 kg/ha hydrogel, water-use efficiency is similar but significantly higher than no hydrogel[34].

Table 3: Interactive effect of irrigation and hydrogel on WUE (kg grain/ha/mm) of wheat

Hydrogel rates	Irrigation levels				
	No	Two	Three	Four	Mean
No Hydrogel	13.0	11.4	11.7	10.4	11.6
2.5kg/ha Hydrogel	14.7	13.3	12.1	11.0	12.8
2.5kg/ha Hydrogel	15.6	14.8	12.9	11.4	13.7
Mean	14.4	13.1	12.2	10.9	

CONCLUSION

Water is an important input for realizing high crop productivity; however, it is becoming the most limiting factor for crop production. Crop production systems that optimize yield, reduce losses and improve water use efficiency are important in sustainable agriculture. Water conservation is a key step to attain sustainable agriculture growth, development and productivity. The problem of optimal capitalization and recovery of water from any source should be seen as a major goal of scientific research. Water will become the "cornerstone" of sustainability and the future of humanity. Water absorbing materials have been reported to be effective tools in increasing water holding capacity. Hydrogel application increases productivity in almost all the test crops (cereals, vegetables, oilseeds, flowers, spices etc.) in terms of crop yield. It also helps improve the quality of agricultural produce in terms of plant biomass, fruit and flower size and colour with improvement in hydro-physical and biological environment of the soil. Hence hydrogels may become a practically convenient and economically feasible option in water-stressed areas for increasing agricultural productivity with environmental sustainability.

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CITATION OF THIS ARTICLE

Shahid B Dar, Dheeraj Mishra, Zahida R and Afshana B B. Hydrogel: To Enhance Crop Productivity Per Unit Available Water Under Moisture Stress Agriculture . Bull. Env. Pharmacol. Life Sci., Vol 6[10] September 2017:129-135