Superabsorbent Polymers (SAPs) Hydrogel: Water Saving Technology for Increasing Agriculture Productivity in Drought Prone Areas: A Review

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ABSTRACT
To improve the soil moisture availability, by reducing the evaporation losses and retaining the moisture in effective rooting zone. The soil application of superabsorbent polymers (SAPs) is found to be the promising methodology in drought prone areas. However, very limited research work done in Indian conditions on this aspect. One of such successfully developed product is ‘Pusa hydrogel’ which is first indigenous semi-synthetic superabsorbent technology for conserving water and enhancing crop productivity and thereby increases the water use efficiency. It performs its wetting or drying cycles over a longer period of time, maintaining its very high water swelling and releasing capacity against soil pressure. Consequently evaporation, deep water percolation and nutrient leaching can be avoided. Under rainfed condition, crops can better withstand drought condition without moisture stress by using hydrogel. 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.

Key words: Hydrogel, Moisture, Polymers.

Hydrogel is a type of polymer which absorbs water or you can say it is a new type of macro molecule synthetic water absorbing polymer material. It is also known as SAP, super soakers, water gel and absorbent gel. As we know that India is an agricultural country, but farmers here have to face many problems while farming due to lack of water, which is increasing with time. Keeping these problems of farmers in mind, a Hydrogel has been prepared by ICAR to relieve them from this problem, which is proving to be very helpful in farming without water in drought prone areas.

Hydrogels are white sugar like polymers which swells in water. Nowadays hydrogels are used extensively to improve mechanization of farming and growing crops to enhance cultivation. They are used in agriculture to obtain higher yields. These polymers are used as soil conditioners, planting, transplanting gels, seed coating for controlled germination and in soil sterilization. This hydrogel is used in places where there is scarcity of water or where the available resources for irrigation of crops are not available. For irrigation, farmers have to buy water due to which the cost of farming becomes very high. In such a situation, this hydrogel is very beneficial for the farmers in water scarcity areas (El-Hady et al., 1981). The literature on the use of superabsorbent polymer and closely related agricultural crops and it’s their effect in growth, yield attributes, nutrient uptake and consumptive use of water has been reviewed and presented in this paper.

Pusa hydrogel
The possibilities of application of superabsorbent polymers (SAPs) in agricultural field have become increasingly important and have been investigated to alleviate certain agricultural problems like water stress condition. One of such developed product is ‘Pusa hydrogel’ which is first successful an indigenous semi-synthetic superabsorbent technology for conserving water and enhancing crop productivity and thereby increases the water use. Pusa Hydrogel is an indigenous product designed and developed by IARI, New Delhi to enhance the crop productivity per unit available water and nutrients, particularly in moisture stress agriculture. Pusa Hydrogel is a semi-synthetic, cross linked,
derived cellulose-graft-anionic polyacrylate superabsorbent polymer. Pusa Hydrogel which is semi-synthetic superabsorbent and absorb water up to 350-500 times of its dry weight in pure water and gradually release it for plant growth with passage of time. Synthetic polymers in the form of crystals or tiny beads available under several trade names such as Pusa Hydrogel, super absorbent polymers, root watering crystals and drought crystals are collectively known as hydrogels (IARI, 2012).

Application of soil conditioners to conserve soil moisture

Many agronomic factors are known to contribute to crop productivity. Water and stress management are the most important factors as they influence the productivity directly. Judicious management of available soil moisture is crucial for improving the crop productivity. Better results seemed to be obtained when the hydrogels area applied, preferably a few inches below soil surface. The determination of amount of gel for the best performance is influenced by many factors including climate, substance type, soil type, crop species etc. The application of polymers to the soil helped in retaining more moisture in the soil, increased water holding capacity and decreased infiltration rate, cumulative evaporation and improving water conservation of soils.

Soil conditioners have been reported to be effective tools in increasing water holding capacity, reducing infiltration rate and cumulative evaporation and improving water conservation of soils (Al-Omran et al., 1987). Soil conditioners both natural and synthetic; contribute significantly to provide a reservoir of soil water to plant on demand in the upper layers of the soil where the root systems normally develop. Organic polymers, mainly polyacrylamides (PAM) and polysaccharides have been used in laboratory studies to maintain the structure and permeability of soils subjected to artificial rainfall (Levy et al., 1991).

Silberbush et al. (1993) reported that the use of soil conditioners has been tested to increase the water holding capacity of soils. Synthetic soil conditioners also possess great potential for restoring soil productivity where the opportunity for irrigation is limited. It has been found that the water storage at different tensions improved significantly in sandy soil treated with gel conditioner (Abedi-Koupai et al., 2008). Shi et al. (2010) stated that poly (ethylene oxide) hydrogel, polycrylamide hydrogel and cross linked poly (ethylene oxide)-co-polyurethane hydrogel were attempted to alleviate the plant damage that resulted from salt induced and water deficient stress (Shi et al., 2010). Hydrogels are three-dimensional networks of super absorbent polymer swelling in aquatic environment, but do not dissolve in solvent (Abedi-Koupai et al., 2008).

Effect of hydrogel on soil physical properties

El-Hady et al. (1981) estimated that, the application of gel as conditioner increased the total porosity, micro pores relative to the total or the macro ones, void ratio, water holding pores, water retention, available water and hydraulic resistivity. It decreased soil bulk density, quickly drained pores, hydraulic conductivity, mean pore diameter, intrinsic permeability, transmissivity and evaporation. Karimi (1993) reported that using of super absorbent could raise capability of saturated hydraulic conductivity of sandy soil. Increase of super absorbent ratios from 0 to 0.8 g kg⁻¹, the unsaturated hydraulic conductivity of soil decreased. The incorporation of superabsorbent polymer with soil improved soil physical properties (El-Amir et al., 1993).

Chana and Shivaprakasham (1996) reported that significant improvement in soil physical properties, namely increased water stable aggregation, reduction in tensile strength and bulk density was detected in the treated soil at the lowest application rate (0.001%) and increased with increasing rate of application. Addition of polymer to peat soil decreased water stress and increased the time to wilt (Karimi et al., 2009). Ekebaf et al. (2011) reported an increase of 171 to 402% in water retention capacity when polymers were incorporated in coarse sand. Showing expansion of the hydrogel particles upon water absorption increased the bulk.
density, aeration and improving drainage, providing faster growth and minimized the danger of root rot. By application of superabsorbent polymer, high water retention capacity and protection against drought was observed by Nazari et al. (2010).

Shahid et al. (2012) studied the effect of different levels of SHNC (superabsorbent hydrogel nano-composites) to evaluate the moisture retention properties of sandy loam soil and concluded that the soil amended with 0.3 and 0.4% w/w of SHNC enhanced the moisture retention significantly at field capacity compared to the untreated soil. Because of swelling nature of super absorbent, that connects fine and coarse pores together and increase capillary porosity (Khodadadi Dehkordi et al., 2013).

**Effect of hydrogel on soil moisture content**

Super absorbent polymer increasing the capacity of water storage in soil (El-Hady and Wanas, 2006) and through reduction of water evaporation from the surface of soil (Akhter et al., 2004). Polyacrylamides in soil were also able to reduce the amount of water loss from soil through evaporation (Abdel-Nasser et al., 2007).

Huttermann et al. (1999) reported that hydrogel application at highest rate (0.4%) changed the water retention and its change in water potential with regard to its water content from typical sand to a loam or even silty clay. The survival rates under 0.4% hydrogel were doubled compared to no hydrogel amendments. The hydrogel also allowed for 19 days tolerating drought. Cookson et al. (2001) evaluated the effect of hydrophilic polymer application and irrigation rates on okra and reported that polymer treated crops required 25 and 50 cent less water in summer and winter, respectively as compared to control condition.

Sivapalan (2001) reported amount of water retained by a sandy soil at 0.03 MPa pressure was significantly increased by 23 and 95% with addition of 0.03 and 0.07% polymer, respectively. Kumaran et al. (2001) reported that hydrophilic polymer significantly reduced the number of irrigation frequency in tomato by increasing water holding capacity of soil.

Azevedo et al. (2002) studied the effects of levels of superabsorbent polymer on irrigation interval and concluded that the polymer increased irrigation interval without damaging the plant. Akhter et al. (2004) recorded that application of hydrogel improves water retention capacity of soils and available water supplies in wheat. Water absorption by hydrogel was rapid and highest which increased the moisture retention at field capacity linearly. Hydrogel delayed wilting 4-5 days in seedling stage compared with control condition.

Bhat et al. (2004) observed that incorporation of 2 g hydrogel reduced the irrigation water by 15 per cent and 3 g hydrogel reduced the irrigation water by 30 per cent in cucumber under stress condition. Koupai et al. (2008) concluded that the hydrogel application (6 g kg⁻¹ soil) increased the number of days (22 days) to reach permanent wilting point (PWP) as compare to control (12 days). Akhter et al. (2004) reported that in barley, wheat and chickpea, addition of hydrogel increased the moisture retention at field capacity linearly in sandy loam and loam soils and thereby the amount of available soil water to plant (AW) increased significantly and linearly in both soils with the addition of hydrogel compared to untreated soils.

Potential benefit of polymers on water storage also depends on the soil texture. Coarse textured soils with large pores tend to retain less water than fine textured soils. The amount of water that may be retained by incorporating the super absorbent polymer would be greater in coarse textured soil than in fine textured soil (Sarvas et al., 2007). The bulk density of loamy and sandy soils reduced with polyacrylamide addition as compared to control while there was small increase in bulk density of clayey soil. Conversely, porosity increased with increasing polyacrylamide doses for clay loam and sandy soil. However, macro pore size increased in clay soil while it decreased in clay loam and sandy loam soil (Uz et al., 2008).

Bhardwaj et al. (2007) stated that hydrogels function as an additional water reservoir for the soil-plant-air system. Application of hydrogels resulted in significant reduction in the required irrigation frequency particularly for coarse-textured soils (Abedi-Koupai et al., 2008). Koupai et al. (2008) observed that use of superabsorbent polymer led to increase in the water holding capacity of the soil. Polymer also showed that they have the ability to increase the water holding capacity of soil while suppressing the evaporation loss of absorbed water from the vacuoles (Vijayalakshmi et al., 2013).

Jammongkan et al. (2010) stated that “hydrogels” can improve the water retention levels of soils. Agaba et al. (2010) stated that superabsorbent polymers (SAPs) can absorb significant amounts (up to 2,000 g/g) of water, therefore are considered very suitable for applications in horticulture and agriculture. Dabhi et al. (2013) reported that super absorbent polymers influenced hydrophilic property, irrigation efficiency, effects under drought stress and optimize water use efficiency of cash crops in arid and semi-arid regions. Application of hydrogel (2.5 kg ha⁻¹) not only improved the productivity but also increased the water-use efficiency, thus ensuring “more crops per drop” of water utilized over control (Jain et al., 2017). Halagalamith and S. Rajkumara (2018) reported that ‘A-1’, ‘JG-11’ and ‘JAKI-9218’ varieties with 2.5 kg ha⁻¹ hydrogel recorded significantly higher WUE and were on par. ‘JG-11’ variety with 0.6 IW/CPE recorded higher gross returns (Rs. 92660/ha), net returns (Rs. 69800/ha) and B:C ratio (3.05). Application of stover mulch significantly recorded higher nutrient content, uptake and protein in pearl millet than control, dust mulch and pura hydrogel and it was at par with pura hydrogel + stover mulch ‘A-1’, ‘JG-11’ and ‘JAKI-9218’ varieties with 2.5 kg ha⁻¹ hydrogel recorded significantly higher WUE and were on par. ‘JG-11’ variety with 0.6 IW/CPE recorded higher gross returns (Rs. 92660/ha), net returns (Rs. 69800/ha) and B:C ratio (3.05).
Effect of hydrogel on growth attributes

Proficiency in water consumption and dry matter production are positive crop reactions to superabsorbent (Woodhouse and Johnson, 1991). Use of hydrophilic polymers as carrier and regulator of nutrient release was helpful in reducing fertilizer losses, while sustaining vigorous crop growth (Mikkelsen, 1994). Nektarios et al. (2004) confirmed the positive influence of polymer on root density and growth by improving physical conditions of soil. Anupama et al. (2005) reported that the application of hydrogel (0.5%) exhibited most prominent growth with plant height, stem diameter, number of leaves per plant, number of flowers per plant and flower size in chrysanthemum.

Super absorbent polymers have been used as water retaining material in agriculture because when incorporated into soil, they can retain large quantities of water and nutrients. These stored water and nutrients are released slowly as required by the crop to improve growth under limited water supply (Yazdani et al., 2007). Yazdani et al. (2008) revealed that the influence of superabsorbent polymer and water stress on the qualitative and quantitative performance of soybean seed protein was found most significant. Orkizra et al. (2009) suggested that hydrogel amendment enhances the efficiency of water uptake and utilization of photosynthetic of plants grown in soils which have water contents close to field capacity.

Patil (2009) observed that the application of superabsorbent polymer under different water gradients significantly increased number of leaves, number of branches and leaf and root biomass over control. Meena (2009) stated that there was an increase in plant height of soybean with application of superabsorbent in soil. Further, a significant increase in the root parameters like root length, root volume, root fresh and dry weight of tomato at harvest was also observed with an increase in concentration of hydrophilic polymer (HP) due to proper maintenance of water for longer duration.

High polymer content with water supply caused opening of stomata for long time, subsequently good fixation of CO₂ resulted in increased dry matter (Khadem et al., 2010). Nazarli et al. (2010) stated that high percentage of moisture retention with the superabsorbent application during the growth period especially in the genesis stage was resulted in high photosynthesis rate and the length of seed filling period.

Islam et al. (2011) reported that plant height, stem diameter, leaf area, biomass accumulation and relative water content in maize increased significantly upto super absorbent polymer at high and very high doses, but optimum dose of super absorbent polymer for maize cultivation was 30 kg ha⁻¹. When polymers are incorporated into soil, they retained large quantities of water and nutrients, which are released as required by the crop. Thus, crop growth was improved with limited water supply.

Rehman et al. (2011) reported that higher germination and better stand establishment of rice in hydrogel amended soil under different sowing techniques as compared to without hydrogel. Agaba et al. (2010) suggested that hydrogel improves plant growth and significantly increased the shoot and root biomass compared to control. Barihi et al. (2013) observed that the use of super absorbent polymer resulted in increased performance of growth indices in greenhouse cucumber. Waly et al. (2015) reported that 1% hydrogel had superiority in all growth and yield attributes of dry rice and produced the tallest plants and the highest number of tillers.

Effect of hydrogel on yield attributes and yield

Magalhaes et al. (1987) found that maize yield increased under superabsorbent polymer application by 11.2% under low, 18.8% under medium and 29.2% under high dose with only half amount of fertilizer. Shivalapalan (2001) found that soybean grown in soil treated with 0.05, 0.1 and 0.2 per cent poly acrylamide (PAM) achieved grain production about 6, 9 and 14 times greater, respectively than control. (Watt and Peake, 2001) revealed that the soil-wetting polymers, incorporated into potato fields, increased 102% water retention in the soil around the root zone and subsequently, 25% increase in tuber yield.

Yazdani et al. (2007) reported that soybean seed yield was significantly increased (5495 kg ha⁻¹) by the application of superabsorbent polymer as compared to control (4172 kg ha⁻¹). Eiasu et al. (2007) found that the pure gel polymer, especially at higher fertilizer rate, improved total and marketable tuber yield. Ghamasi et al. (2009) reported that application of superabsorbent polymers helped to alleviate drought stress and increased grain number and grain weight in maize.

Khadem et al. (2010) also recommended that the adding superabsorbent polymer can linearly increase 1000-seed weight of corn and soybean crops. Ali (2011) reported that the marketable yield of maize increased due to mixing of compost with CMC and incorporating into the soil. Vijayalakshmi et al. (2012) suggested that use of 0.75% (w/w) water soluble polymers with 50% Attainable Moisture Depletion (AMD) to tomato in sandy loam soil produced the highest yield (59.6 t ha⁻¹) and maximum water use efficiency (153.6 kg m⁻³).

Dabhi et al. (2013) reported that super absorbent polymers influenced yield of cash crops in arid and semi-arid regions. Waly et al. (2015) revealed that application of 1% hydrogel in dry rice produced the highest number of grains panicle⁻¹, the heaviest panicle, the highest grain yield, the highest biological yield pot⁻¹, the highest harvest index and the highest protein % in grains. Application of Pusa hydrogel at 2.5 kg ha⁻¹ in furrow at the time of sugarcane planting helped in better germination and vigour of the crop resultantly enhanced cane yield, CCS yield and IWUE (Ishwar Singh et al., 2017). Hydrogel was applied at the rate of 5 kg ha⁻¹ and observations related to various plant growth parameters and yields were recorded. The plant population in hydrogel plots increased by 22% compared to the non-hydrogel treated plots. The effective tillers, plant...
height, ear length and grains per ear significantly improved due to hydrogel application. The total yield as well as grain yield increased significantly after hydrogel amendment (Roy et al., 2019).

**CONCLUSION**

The soil application of super absorbent polymers (SAPs) is found to be the promising methodology in rainfed areas. The application of polymers to the soil helped in retaining more moisture in the soil, increased water holding capacity and decreased infiltration rate, cumulative evaporation and improving water conservation of soils. To improve the soil moisture availability, by reducing the evaporation losses and retaining the moisture in effective rooting zone, the Hydrogel will nourish the roots near the roots for a long time by soaking the water and will not allow the plants to lack water. Under rainfed condition, crops can better withstand drought condition without moisture stress by using hydrogel and it reduces irrigation frequency. It helps to save labour cost (Cost during irrigation and fertilizing), reduces overuse of pesticides and fertilizers. They help in binding loose soil and forming loams. Also reduces, the seedling mortality by several folds in nurseries.

**Future research thrust**

- The dosage of hydrogel for diverse soil types needs to be quantified in different agro climatic conditions in India.
- The mechanism of water absorption and release pattern of hydrogel needs in depth study.
- The possibilities to develop farm equipments for the application of hydrogel in the sub-soil layers to be explored.

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