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# 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,

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derivatized cellulose-graft-anionic polyacrylate superabsorbent polymer. Pusa Hydrogel which is semi-synthetic super-absorbent 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, polyacrylamide 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. Application of superabsorbent under drought conditions prevents from the loss of water and nutrients and creates favourable conditions for corn growth and finally increases corn yield toward consumed water and increased production index and its value (Khodadadi Dehkordi *et al.*, 2013) The desired amount of hydrogel (5 kg $ha^{-1}$) was mixed with dry and fine sand of less than 0.25 mm size in 1:10 ratio, in order to distribute uniformly along the row. Sand mixed hydrogel was applied in line where seed was sown (Narjary *et al.*, 2013).

## Characteristics of superabsorbent polymer - hydrogel

In India, a few research works has been done on the use of polymers in agriculture. The dose of polymers varies from 2.5 to 60 kg $ha^{-1}$ and depends 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 (Dexter and Miyamoto, 1959). 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) Cross-linked polyacrylamides and Acrylamide-acrylate co-polymers.

Materials having the capacity to absorb water 20 times more than their weight is considered as superabsorbent (Abedi-Koupai *et al.*, 2004). But due to development of more cross-linked polymer with high water holding capacity (400 times and even up to 2000 times of their weight) and comparatively low cost has rejuvenated interest on the use of polymer in agriculture. 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 (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).

Chan and Sivapragasam (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). Ekebafe *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 Nazarli *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 per 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).

Jamnongkan *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). Halagalimath 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 pearlmillet than control, dust mulch and pusa hydrogel and it was at par with pusa 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. Orikiriza *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 $CO_2$ 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. Sivapalan (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. Ghamsari *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.

## REFERENCES


Abdel-Nasser G., Al-Omran A.M., Falatah A.M., Sheta A.S. and Al-Harbi A.R. (2007). Impact of natural conditioners on water retention, infiltration and evaporation characteristics of sandy soil. Journal of Applied Sciences. 7: 1699-1708.

Abedi-Koupai, J., Eslamian, S.S. and Asad Kazemi, J. (2004). Enhancing the available Water Content in Unsaturated Soil Zone using Hydrogel, to Improve Plant Growth Indices. Ecohydrology and Hydrobiology. 8: 3-11.

Abedi-Koupai, J., Sohrab, F. and Swarbrick, G. (2008). Evaluation of hydrogel application on soil water retention characteristics. Journal of Plant Nutrition. 3: 317-331.

Agaba, H., Baguma Orikiriza, L.J., Osoto Esegu, J.F., Obua, J., Kabasa, J.D. and Hüttermann, A. (2010). Effects of hydrogel amendment to different soils on plant available water and survival of trees under drought conditions. Clean-Soil, Air, Water. 38: 328-335.

Akhter, J., Mahmood, K., Malik, K., Mardan, A., Ahmad, M. and Iqbal, M. (2004). Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. Plant Soil Environment. 50: 463-469.

Ali, L.K.M. (2011). Significance of applied cellulose polymer and organic manure for ameliorating hydro-physico-chemical properties of sandy soil and maize yield. Australian Journal of Basic and Applied Sciences. 5: 23-35.

Al-Omran, A.M., Mustafa, M.A. and Shalaby, A.A. (1987). Intermittent Evaporation from Soil Columns as Affected by a Gel-forming Conditioner 1. Soil Science Society of America Journal. 5: 1593-1599.

Anupama, M.C., Singh, R., Kumar, B.S. and Kumar, P.A. (2005). Performance of new super absorbent polymer on seedling and post planting growth and water use pattern of Chrysanthemum under controlled environment. Acta Horticulturae. 618: 215-224.

Azevedo, T.L., Bertonha, A., Goncalves, A.C.A., Freitas, P.S.L., Rezende, R. and Frizzone, J.A. (2002). Levels of super absorbent polymer, irrigation interval and coffee plant growth. Acta Scientiarum. 24: 1239-1243.

Barihi, R., Panahpour, E. and Beni, M.H.M. (2013). Super Absorbent Polymer (Hydrogel) and its Application in Agriculture. World of Sciences Journal. 1: 223-228.

Bhardwaj, A.K., Shainberg, I., Goldstein, D., Warrington, D.N. and J Levy, G. (2007). Water retention and hydraulic conductivity of cross-linked polyacrylamides in sandy soils. Soil Science Society of America Journal. 71: 406-412.

Bhat, A.I., Faisal, T.H., Madhubala, R., Hareesh, P.S. and Pant, R.P. (2004). Purification, production of antiserum and development of enzyme linked immunosorbent assay-based diagnosis for Cucumber mosaic virus infecting black pepper (*Piper nigrum* L.). Journal of Spices and Aromatic Crops. 13: 16-21.

Chan, K.Y. and Sivapragasam, S. (1996). Amelioration of a degraded hardsetting soil using an anionic polymeric conditioner. Soil Technology. 9: 91-100.

Cookson, P., Abdelrahman, H. and Hirsbrunner, P. (2001). Effect of hydrophobic polymer application and irrigation rates on yield of field grown okra. Journal of Agricultural and Marine Sciences. 6: 67-75.

Dabhi, R., Bhatt, N. and Pandit, B. (2013). Superabsorbent polymersan innovative water saving technique for optimizing crop yield. International Journal of Innovative Research in Science, Engineering and Technology. 2: 5333-5340.

Dexter, S.T. and Miyamoto, T. (1959). Acceleration of water uptake and germination of sugarbeet seedballs by surface coatings of hydrophilic colloids 1. Agronomy Journal. 51: 388-389.

Eiasu, B.K., Soundy, P. and Hammes, P.S. (2007). Response of potato (*Solarium tuberosum*) tuber yield components to gel polymer soil amendments and irrigation regimes. New Zealand Journal of Crop and Horticultural Science. 35: 25-31.

Ekebafe, L.O., Ogbeifun, D.E. and Okieimen, F.E. (2011). Effect of native cassava starch-poly (sodium acrylate-co-acrylamide) hydrogel on the growth performance of maize (*Zea mays*) seedlings. American Journal of Polymer Science. 1: 6-11.

El-Amir, S., Helalia, A.M. and Shwaky, M.E. (1993). Effects of acryhope and aquastore polymers on water regime and porosity in sandy soil. International Agrophysics. 6: 19-25

El-Hady, O.A. and Wanas, S.A. (2006). Water and fertilizer use efficiency by cucumber grown under stress on sandy soil treated with acrylamide hydrogels. Journal of Applied Science Research. 2(12): 1293-1297.

El-Hady, O.A., Tayel, M.Y. and Lotfy, A.A. (1981). Super Gel as a soil conditioner II-Its effect on plant growth, enzymes activity, water use efficiency and nutrient uptake. Paper presented at the 3rd International Symposium on Water supply and Irrigation in the open and under Protected Cultivation 119.

Ghamsari, B.M., Akbari, G.A., Zohorian, M.J. and Nikniaee, A.B. (2009). An evaluation of growth and yield of forage corn with application of different levels of super absorbent polymer (SUPERAB A200) and under drought stress. Iranian Journal of Field Crop Science. 40: 1-8.

Halagalimath S.P. and Rajkumar S. (2018). Response of chickpea (*Cicer arietinum* L.) varieties to irrigation and hydrogel application in Vertisols. Legume Research. 41(2): 259-262.

Huttermann, A., Zommorodi, M. and Reise, K. (1999). Addition of hydrogels to soil for prolonging the survival of Pinus halepensis seedlings subjected to drought. Soil and Tillage Research. 50: 295-304.

IARI. (2012). Pusa Hydrogel: An Indigenous semisynthetic super--absorbent technology for conserving water and enhancing crop productivity. Indian Agricultural Research Institute, New Delhi, India.

Ishwar Singh, Verma, R.R. and Srivastava, T.K. (2018). Growth, Yield, Irrigation Water Use Efficiency, Juice Quality and Economics of Sugarcane in Pusa Hydrogel Application Under Different Irrigation Scheduling. Sugar Tech. 20: 29-35.

Islam, M.R., Hu, Y., Mao, S., Jia, P., Eneji, A.E. and Xue, X. (2011). Effects of water saving superabsorbent polymer on antioxidant enzyme activities and lipid peroxidation in corn (*Zea mays* L.) under drought stress. Journal of the Science of Food and Agriculture. 91: 813-819.

Jain, N.K., Meena H.N. and Bhaduri, D. (2017). Improvement in productivity, water-use efficiency and soil nutrient dynamics of summer peanut (*Arachis hypogaea* L.) through use of polythene mulch, hydrogel and nutrient management. Communicatons in Soil Science and Plant Analysis. 48: 549-564.

Jamnongkan, Tongsai, Kaewpirom and Jjjsupranee. (2010). Potassium release kinetics and water retention of controlled-release fertilizers based on chitosan hydrogels. Journal of Polymers and the Environment. 18: 413-421.

Karimi, A. (1993). Evaluation of effect of corrective material of Igeta on Sunflower growth. M.Sc. (Agri.) Thesis, Agricultural College, Tehran University, Farsi.

Karimi, A., Noshadi, M. and Ahmadzadeh, M. (2009). Effects of super absorbent polymer (igeta) on crop, soil water and irrigation interval. JWSS-Isfahan University of Technology. 12: 403-414.

Khadem, S.A., Galavi, M., Ramrodi, M., Mousavi, S.R., Rousta, M.J. and Rezvani-Moghadam, P. (2010). Effect of animal manure and superabsorbent polymer on corn leaf relative water content, cell membrane stability and leaf chlorophyll content under dry condition. Australian Journal of Crop Science. 4: 642.

Khodadadi Dehkordi, D., Kashkuli, H.A. and Naderi, A. (2013). Evaluation of effect of superabsorbent on saturated and unsaturated soil hydraulic conductivity and estimate index of corn yield. Advances in Environmental Biology. 7: 3252-3259.

Koupai, J.A., Eslamian, S.S. and Kazemi, J.A. (2008). Enhancing the available water content in unsaturated soil zone using hydrogel, to improve plant growth indices. Ecohydrology and Hydrobiology. 8: 67-75.

Kumaran, S.S., Natarajan, S., Muthvel, I. and Sathiyamurthy, V.A. (2001). Standardisation of hydrophylic polymers on growth and yield of tomato. Madras Agricultural Journal. 88: 103-105.

Levy, G.J., Ben-Hur, M. and Agassi, M. (1991). The effect of poly--acrylamide on runoff, erosion and cotton yield from fields irrigated with moving sprinkler systems. Irrigation Science. 12: 55-60.

Magalhaes, J.R., Wilcox, G.E., Rodrigues, F.C., Silva, F. and Rocha, A.F. (1987). Plant growth and nutrient uptake in hydrophilic gel treated soil. Communications in soil science and plant analysis. 18: 1469-1478.

Meena, M.K. (2009). Influence of hydrophilic polymer (Luquasorb) on plant growth and physiology in tomato (*Lycopersicon esculentum* L. Mill). M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Dharwad.

Mikkelsen, R.L. (1994). Using hydrophilic polymers to control nutrient release. Fertilizer research. 38(1): 53-59.

Narjary, B., Aggarwal, P., Kumar, S. and Meena, M.D. (2013). Significance of hydrogel. Indian Farming. 62: 15-17.

Nazarli, H., Zardashti, M.R., Darvishzadeh, R. and Najafi, S. (2010). The effect of water stress and polymer on water use efficiency, yield and several morphological traits of sunflower under greenhouse condition. Notulae Scientia Biologicae. 2: 53-58.

Nektarios, P.A., Nikolopoulou, A.E. and Chronopoulos, I. (2004). Sod establishment and turfgrass growth as affected by urea-formaldehyde resin foam soil amendment. Scientia horticulturae. 100: 203-213.

Orikiriza, L.J.B., Agaba, H., Tweheyo, M., Eilu, G., Kabasa, J.D. and Huttermann, A. (2009). Amending Soils with Hydrogels Increases the Biomass of Nine Tree Species under Non water Stress Conditions. Clean-Soil, Air, Water. 37: 615-620.

Patil, A.A. (2009). Influence of super absorbent polymer on plant growth and productivity in cabbage (*Brassica oleracea* var. *capitata* L.). M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Dharwad.

Rehman, A., Ahmad, R. and Safdar, M. (2011). Effect of hydrogel on the performance of aerobic rice sown under different techniques. Plant Soil and Environment. 57: 321-325.

Roy, T., Kumar, S., Chand, L., Kadam, D.M., Bihari, B., *et al.* (2019). Impact of Pusa hydrogel application on yield and productivity of rainfed wheat in North West Himalayan region. Current Science. 116: 1246-1251.

Sarvas, M., Pavlenda, P. and Takacova, E. (2007). Effect of hydrogel application on survival and growth of pine seedlings in reclamations. Journal of Forest Science. 53: 204-209.

Shahid, S.A., Qidwai, A.A., Anwar, F., Ullah, I. and Rashid, U. (2012). Improvement in the Water Retention Characteristics of Sandy Loam Soil Using a Newly Synthesized Poly (acrylamide-co-acrylic acid)/AlZnFe2O4 Superabsorbent Hydrogel Nanocomposite Material. Molecules. 17: 9397.

Shi, Y., Li, J., Shao, J., Deng, S., Wang, R., *et al.* (2010). Effects of Stockosorb and Luquasorb polymers on salt and drought toleranceof *Populus popularis*. Scientia Horticulturae. 124: 268-273.

Silberbush, M., Adar, E. and De Malach, Y. (1993). Use of an hydrophilic polymer to improve water storage and availability to crops grown in sand dunes I. Corn irrigated by trickling. Agricultural Water Management. 23: 303-313.

Sivapalan, S. (2001). Effect of a polymer on growth and yield of soybeans (*Glycine max*) grown in a coarse textured soil. Paper presented at the Irrigation 2001 Regional Conference, 11-12 July Toowoomba, Queensland, Australia.

Uz, B.Y., Ersahin, S., Demiray, E. and Ertas, A. (2008). Analyzing the soil texture effect on promoting water holding capacity by polyacrylamide. International Meeting on Soil Fertility Land Management and Agroclimatology. (Special Issue): 209-215.

Vijayalakshmi, Nemichandrappa, M., Reddy, K.S. and Ayyanagowdar, M.S. (2012). Effect of polymers on moisture retention and soil water holding capacity. Karnataka Journal of Agricultural Sciences. 25: 469-471.

Waly, A., El-Karamany, M.F., Shaaban, A.M., Bakry, A.B. and Elewa, T.A. (2015). Utilization of hydrogel for reducing water irrigation under sandy soil condition 2-Preliminary study: yield and yield components of rice and barley in sandy soil as affected by hydrogel. Research Journal of Pharmaceutical Biological and Chemical Sciences. 6: 1018-1024.

Watt, S. and Peake, R. (2001). Potato production on sandy soil in Australia: PIRSA rural solutions.http://www.sardi.sa.gov.au/pages/horticulture/pathology/hortpnpotsand.htm:sectID=323andtempID=152.

Woodhouse, J. and Johnson, M.S. (1991). Effect of superabsorbent polymers on survival and growth of crop seedlings. Agricultural water management. 20: 63-70.

Yazdani, F., Alahdadi, A. and Akbari, B.M.R. (2008). Effect of Super absorbent polymer (Terawatt A200) and different levels of drought stress on soybean yield and yield components. Research in Agriculture and Horticulture and Construction. (75).

Yazdani, F., Allahdadi, I. and Akbari, G.A. (2007). Impact of superabsorbent polymer on yield and growth analysis of soybean (*Glycine max* L.) under drought stress condition. Pakistan Journal of Biological Sciences. 10: 4190-4196.