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SUPER ABSORBENT POLYMERS - AN INNOVATIVE WATER SAVING TECHNIQUE FOR OPTIMIZING CROP YIELD

Rajiv Dabhi[1], Neelkanth Bhatt[2] and Bipin Pandit[3]

P.G. Student, Dept. of Civil Engineering, L. E. College, Morvi, Gujarat, India[1]

Assistant Professor of Civil Engineering, Dept. of Civil Engineering, L. E. College, Morvi, Gujarat, India[2]

Professor and Head of Civil Engineering Dept., L. E. College, Morvi, Gujarat, India[3]

Abstract: Many arid and semi arid regions are facing the problems of uncertain and inadequate rain fall. Spatially diversified soil characteristics, shortage of large agricultural lands and underprivileged condition of farmers do not allow them to adopt advantageous and economical application of traditional irrigation methods as well as micro irrigation techniques (drip and sprinkler irrigation). Though, not much research in India has been undertaken on the use of Super Absorbent Polymers (SAP) in agriculture, the researchers world over (specifically Iran, China, Europe and USA) have extensively worked on utilizing SAP for increasing water use efficiency and enhancing crop yield. Various studies have strongly recommended that soil conditioning with Super Absorbent Polymers could be an innovative facet in the field of agriculture, which works as miniature water storage reservoirs. Research evidences suggest that problems associated with traditional micro irrigation and the factors which are catalyst in practicing efficient irrigation techniques can be taken care of by conditioning the soil with SAP. Better water management can be attained with the application of polymers and considerable water saving can be done without compromising the crop yield. Present literature review has been conducted to have a quick access in understanding various properties of Super Absorbent Polymers (SAP, Hydro-gels, and Polymers) to be used in agriculture. Science of SAP, hydrophilic property, irrigation efficiency, effects under drought stress, effects over the morphological features of the plant, optimum use of fertilizers, biodegradability and application rates under different condition are thoroughly reviewed. The present review would provide an initiative for the experimental research on use of SAP and its rate of application to optimize water use efficiency and the yield of cash crops in arid and semi-arid regions.

Keywords: Super Absorbent Polymer, Water absorption, Irrigation efficiency, Drought stress, Crop yield

I. INTRODUCTION

With the fast decline of irrigation water potential and continued expansion of population and economic activity in most of the countries, which are located specially in the arid and semi-arid regions of the world, the problems of water scarcity is expected to be aggravated further as studied by Rosegrant, W. Mark,(1997)[1] and Biswas,(1993, 2001) [2, 3]. As per the global survey, the worst affected areas would be the semi-arid regions of Asia (India), the Middle-East and Sub-Saharan Africa, all of which are already having heavy concentration of population living below poverty line. By 2025 the problem of water scarcity in India will be severest. Saleth,(1996)[4] and The central water commission (CWC), Govt. of India,(1996,1998,2004,2004)[5] has also concluded that owing to various reasons the demand for water for different purposes has been continuously increasing in India, but the potential water available for future use has been declining at a faster rate. The agricultural sector (irrigation), which currently consumes over 80 percent of the available water in India, continues to be the major water-consuming sector due to the intensification of agriculture as predicted by Saleth, (1996)[4], MOWR, (1999)[6] and Iyer, (2003)[7]. Though India has the largest irrigated area in the world, the coverage of irrigation is only about 40 percent of the gross cropped area as of today. One of the main reasons for the low coverage of irrigation is the predominant use of traditional methods of irrigation, where water use efficiency

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is very low due to various reasons. Available estimates indicate that water use efficiency under flood method of irrigation is only about 35 to 40 percent because of enormous transportation and distribution losses as studied by Rosegrant,(1997),[1] and INCID,(1994)[8]. As agricultural sector is one of the largest consumers of water, the demand of water has been consistently increasing from various sectors like domestic; industry etc. due to the population growth and such uses can often be at the cost of agriculture. The dominant method of irrigation practiced in large parts of the country is surface irrigation under which crop utilize only less than one half of the water released and remaining half gets lost in conveyance, application, runoff and evaporation. T.B.S. Rajput and Neelam Patel,(2012)[9] has inferred that micro irrigation methods like drip and sprinklers need to be employed for efficient distribution and application of water for crop production. High initial cost, inadequate subsidy amount, difficulty in getting subsidy amount, lack of availability of technical input and after sale services, clogging of dripper and cracking of laterals, damages due to rats and squirrels, high cost of spares and components, discrimination in subsidy distribution among different categories of farmers etc. are some of the major constraints faced by Indian farmers in the opinion of Dr. K. T. Chandy,[10] S.Mahendra Dev,(2012)[11] has noted that in India around 98 million out of total 120 million farm holdings are small and marginal farmers; the sustainability of these farmers is crucial for livelihoods in rural areas and for the entire country and the net farm income is also low for small holding. Therefore, the stress on agricultural development in the present has shifted to the sustainable use of land, water and plant resources in agriculture. The major goal of the present day agriculture is to maximize land and water productivity without threatening the environment and the available natural resources.

In this regards a detailed review study about the application of Super Absorbent Polymers in the field of agriculture especially for the small and marginal farmers living under arid and semi arid regions, highlighting latest research inclination towards the various parameters like soil, water and plant.

During the last few years, the science and technology of reactive functionalized Super Absorbent Polymers (SAP, Hydro-gels, and Polymers) have received considerable interest as one of the most exciting areas of polymer chemistry for the production of improved materials. Ahmed A.,(1990)[12], and L. O. Ekebafe *et al.*,(2011)[13] in their respective studies on SAP have found that SAP has extensive applications as reactive materials based on the potential advantages of the specific active functional groups and the characteristic properties of the polymeric molecules.

II. BASICS AND SCIENCE BEHIND SAP

Mohammad J. Zohuriaan-Mehr and Kourosh Kabiri,(2008)[14] Waham Ashaier Laftah, Shahrir Hashim, and Akos N. Ibrahim,(2010)[15] have experimentally concluded that SAP materials are hydrophilic networks that can absorb and retain huge amounts of water or aqueous solutions. They can uptake water as high as 100,000%. Common SAPs are generally white sugar-like hygroscopic materials can be used for agricultural use, experienced by. Francesco Puoci, Francesca Iemma, Umile Gianfranco Spizzirri, Giuseppe Cirillo, Manuela Curcio and Nevio Picci,(2008)[16] have found that in agricultural field, polymers are widely used for improving irrigation efficiency; SAP materials has smart delivery systems it can help the agricultural industry to combat viruses and other crop pathogens, functionalized polymers were used to increase the efficiency of pesticides and herbicides, allowing lower doses to be used and to indirectly protect the environment through filters or catalysts to reduce pollution and clean-up existing pollutants.

Figure (1) shows diagrammatic representation of part of the polymer network, cross-linking of polymers, and the root zone of plant developed under SAP mixed soil structure. The polymer backbone in SAP is hydrophilic i.e. 'water loving' because it contains water loving "carboxylic acid" groups (– COOH). Mark Elliott, (2010) [17] found that when water is added to SAP there is a polymer/solvent interaction; hydration and the formation of hydrogen bonds.

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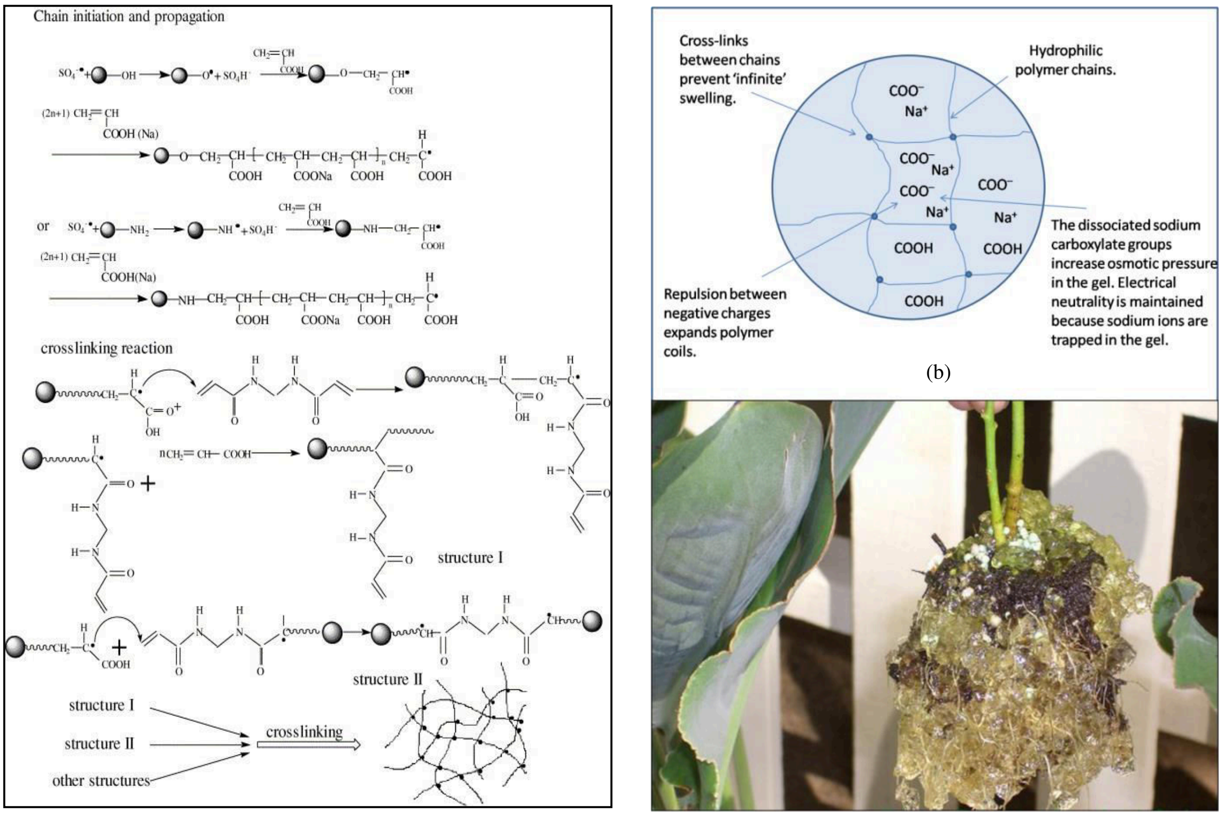

(a) (c)

Fig. 1 (a) Source: Chemical Cross linking procedure of SAP – Chain initiation and propagation, Website: http://www.functionalpolymers.basf.com/portal/streamer?fid=291074, (b) Modified from Mark Elliot, SAP, (2010), Part polymer network, (c) Root Zone development of the plant with SAP

III. WATER ABSORPTION OF SAP

Prof. Feng Jin-Cheng and Prof. Ji Jing-Qiu, [18] have inferred that Polymers works as water conservative reservoirs, which works near the root mass zones of the plant; On watering, these polymers expand to around 200-800 times of its original volume, further irrigation water or rainwater can be collected, stored, and then released gradually for crop requirements over a fairly long duration between water applications. The authors also further concludes that Polymers when mixed with the soil structure create good air permeability in soil, improves water absorption property of soil and fertilizer conservation capacity hence economy in irrigation can be attained. It also decreases loss of fruits and vegetables caused by the insects by 10-30%. Texas Department of Transportation Research and Technology Implementation Office, (2013) [19] also analyzed and published their performance report regarding the use of the polymers and accordingly recommended that SAP is helpful in improving water retention in soil. Further, Fonteno W. C. and Bilderback [20] have also noted that SAP can be used to improve agricultural areas as it can absorb and store up to 400 times their own weight of water. Morante, J., (2009) [21] extends the scope of SAP to use rainwater and deliver to plants until the next storm. These products have been tested in Spain by Soler-Rovira, J., Usano-Martinez, M. C., Fuentes-Prieto I., Arroyo-Sanz, J. M. and Gonzalez-Torres, F.,(2006) [22] and in Iran by Koupai, J. A., Eslamian, S. S. and Kazemi, J. A.,(2008) [23] and it was observed that use of SAP leads to increase in the soil water holding capacity and improves germination rates. Hydrogels have been proven effective in different types of soils. Similar experiments by Abd El-Rehim, H. A., Hegazy, E. S. A., and Abd El-Mohdy, H. L.,(2004) [24] reveals that the water retention of sandy soils may improve considerably increasing the plant performance on those soils. On small scales, these products might be useful to enhance rainfall retention in the soil, especially on slopes that allow little runoff. The polymers absorb water as it infiltrates through the soil.

IV. POLYMERS FOR WATER CONSERVATION IN AGRICULTURAL LANDS

Fidelia Nnadi and Chris Brave, (2001) [25] have observed that improved water retention capacity can be achieved by the amendment of SAP with various percentage of dosage in to the soil structure by weight. Water retention capacity of soil can be increased by 50% to 70%. Experimental investigations on soil carried out by M. Yangyuoru, E. Boateng, S.G.K. Adiku , D. Acquah, T.A. Adjadeh and F. Mawunya, (2006) [26] conditioned with different treatments of polymers suggests that extensive retention of water by the SAP was observed which would otherwise lost due to evaporation and percolation. In an another study by W. Bai, H. Zhang, B. Liu and Y. Wu & J. Song, (2010) [27] consequences on the physical and chemical properties of soil under alternating wetting and drying condition were studied using different types of SAPs in different concentrations. The study suggested that soil moisture increased by 6.20 - 32.80% with SAP application, while soil bulk density was reduced by 5.50–9.40% relative to the control, especially with a moderate water deficit when the relative soil moisture contents were about 40–50%. Further, experimental studying of saturated soil water content, saturated soil hydraulic conductivity and soil water diffusivity of the soil with SAP application, it was found that saturated water volumetric content increased significantly up to 0.186 cm^3, which is meaningful for improving agricultural water use efficiency in the arid and semi-arid areas. Both saturated hydraulic conductivity and diffusivity had a significant reduction mainly because SAPs repeatedly absorbed and desorbed water. The water absorbing and desorbing capacity of SAPs showed a downward trend with time and outside water condition. Under a relatively stable water condition, such capacity of SAPs reduced more slowly. Therefore, the saturated water volumetric content of the mixed SAP and soil samples decreased gradually but still higher than or close to that of the ordinary soil, and the hydraulic conductivity and diffusivity increased gradually but still respectively lower than those of the ordinary soil. These studies provided by Yuguo Han , Xinxiao Yu, Peiling Yang, Bo Li, Lei Xu and Chengzhi Wang, (2013) [28] an important foundation for the encouragement of SAPs in the arid and semi-arid areas. Experiments by Martin Makgose Maboko, (2006)[29], Bakass M, Mokhlisse A, Lallemant M,(2002)[30], Liyuan Yan and Yan Shi,(2013)[31] in sandy soil (macroporous medium) also resulted in greater soil efficiency and positive impact on the yield of the crop. SAP potentially influences soil permeability, density, structure, texture, evaporation, and infiltration rates of water through the soils. Abd EI-Rehirn HA, Hegazy ESA, Abd El- Mohdy HL, (2004) [32] has concluded that Hydro-gels reduce irrigation frequency and compaction tendency, stop erosion and water runoff and increase the soil aeration and microbial activity.

V. INCREASING IRRIGATION EFFICIENCY BY SAP

Research carried out by Hossein Nazarli, Mohammad Reza Zardashti, Reza Darvishzadeh and Solmaz Najafi, (2010) [33] suggests that with the use of SAP in irrigation practice, water stress significantly alter in decreasing the number of leaves per plant, chlorophyll content, seed yield and water use efficiency. Whereas the application of super absorbent polymer moderated the negative effect of deficit irrigation, especially in high rates of polymer (2.25 and 3 g/kg of soil) Polymer have the best effect to all characteristics of the plants in all levels of water stress treatment and it is strongly suggests that the irrigation period of cultivation can be increased by application of polymer. In term of water conservation and optimize water use efficiency where water scarcity is a common problem, SAP can be used as a water conservator in agriculture as suggested by Alessandro Sannino, (2008) [34]. Another study on the effects of SAP by S. Shooshtarian, J. Abedi-Kupai, A. TehraniFar, (2011) [35] on the physical characteristics of soil and plant species (flowers and ground cover plants, turf grasses, trees and shrubs) it was found that reaction and amount of irrigation efficiency enhanced after using SAP for green spaces within arid and semi arid regions.

VI. SAP TREATMENT TO REDUCE DROUGHT STRESS

The effect of super absorbent polymer and different levels of irrigation on characteristics of the plants it was observed that the effect of interaction between super absorbent and water stress was significant and a major decrease was observed with increase in stress level by Atiyeh Oraee and Ebrahim Ganji Moghadam, (2013) [36]. Further the authors studied other parameters such as the highest plant height, number and surface area of the leaf, fresh and dry weight and diameter of plant was related to irrigation after 4 days with 3% polymer application and the lowest was related to irrigation after 12 days with no application of polymer the study indicates that using SAP controlled of relationship soil, water and plant, decrease water stress; drought stress causes molecular damage to plants, either directly or indirectly through formation of reactive oxygen species (ROS).

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Alteration of antioxidant enzymes activities is an element in the defense process. Changes in antioxidant enzymes activities and seed yield in the plants were investigated by H. Nazarli, M.R. Zardashti, R. Darvishzadeh and M. Mohammadi, (2011) [37] under drought stress and super absorbent synthetic polymer application and suggested that application of polymers could be advantageous against drought stress, and could protect plants in drought stress conditions. After adding SAP to the soil of pots in deepness of root development and applying drought stress in four different leaf stage the results indicated that water stress significantly decreased the number of leaves per plant, chlorophyll content, dry weight, relative water content and Water Use Efficiency, whereas the application of SAP can also compensate the negative effect of drought stress, especially in high rates of polymer application (0.2 (%) and 0.4 (%) (g/kg)).

It is strongly suggested by Leila Keshavars, Hasan Farahbakhsh and Pooran Golkar, (2012) [38)] that the irrigation intervals could be increased by application of SAP. Property of high water retention capacity and protection against drought was also observed by H. Nazrali, F. Faraji and M.R. Zardahsti, (2011) [39]. As referred above, drought stress leads to production of Oxygen radicals, which results in increased lipid perioxidation and oxidative stress in the plant, but with the use of SAP could reserve different amount of water in itself and ultimately increases the soil ability of water retention and preserving and at last in water deficiency as concluded in the experimental study of H.R.Tohidi, A.H.Shirani-Rad, G.Nour-Mohammadi, D.Habibi and M.Marshhadi-Akbar-Boojar, (2009)[40] .Considerable decrease in drought stress was also observed during another study by Javad Khalili Mahalleh, Hossein Heidari Sharif Abad, Gorban Nourmohammadi. Farrokh Darvish, Islam Majidi Haravan, Ebrahim Valizadegan, (2011) [41] the effects of using SAP on yield, yield components and water use efficiency of silage corn.

VII. SAP TO ENHANCE FERTILIZER EFFICIENCY

M. Robiul Islam, Xuzhang Xue, Sishuai Mao, Xingbao Zhao, A. Egrinya Eneji and Yuegao Hu, (2011) [42] concluded that optimum use of fertilizer, herbicides and germicides is also considered to be one of the major constraints in designing efficient irrigation technology. While making effort in arid and semiarid regions of northern China, there was an increasing interest in using reduced rate of chemical fertilizer along with SAP for field crop production by evaluating the effectiveness of different rates of SAP, it was observed that application by 11.2% under low 18.8% under medium and 29.2% under high rate with only half amount (150 kg ha-1) of fertilizer compared with control plants, which received conventional standard fertilizer rate (300 kg ha-1). At the same time plant height, stem diameter, leaf area, biomass accumulation and relative water content as well as protein and sugar contents in the grain also increased significantly following SAP treatments. The authors also suggested that, the application of SAP at 15 kg ha-1 plus only half the amount of conventional fertilizer rate (150 kg ha-1) would be a more appropriate practice for sustainable crop production under arid and semiarid conditions and the regions with the similar ecologies; moreover, polymers are safe and non-toxic, it also reduce excessive nutrient loss from soil thereby preventing pollution of agro ecosystem. Another field experiment by the same authors suggest that during two successive years (2004, 2005) the effect of treating a virgin sandy soil with hydrophilic polymers on yield and water and fertilizer use efficiency by plants produced beneficial effects for reducing water consumption and increasing both water and fertilizers use efficiency by plants. O. A. El-Hady and Sh. A. Wanas, (2006) [43] have concluded that SAP can be used for conserving irrigation water and increasing the agricultural potentialities of sandy soils under the severe conditions of deserts (i.e. the limited water resources and the inadequate water retention and low fertility of such soil).

VIII. BIODEGRABABILITY OF SAP

While studying about the soil amendment elements their post consequences must be known to the users as it may be absorbed by the root and ultimately penetrates in to the fruits and any crops and may cause noxious effect on the consumers. Studies carried out by Fidelia N. Nnadi, (2012) [44] have proven that SAP is sensitive to the action of ultraviolet rays, which by breaking bonds; degrade the polymer into oligomers (molecules of much smaller size). These polyacrylates (type of agricultural SAP) thus becomes much more sensitive to the aerobic and anaerobic processes of microbiological degradation, therefore degrade naturally in soils (up to 10% to 15% per year), in water, carbon dioxide, and nitrogen compounds. The polyacrylates is too voluminous to be absorbed into the tissues and walls of plants that it has no potential for bioaccumulation. It is ideal solution for containers, hanging plants, and houseplants, and it has also shown its effectiveness in large-scale farming, especially at the time of germination and development of the root network due to good aeration of the soil.

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IX. REDUCTION IN ABSORPTION RATE OF SAP

A polymer absorbs water with the repulsion of cross linking chains. Various researchers have worked to analyze this property and they have found that the rate of water absorbency of different commercially available hydrophylic polymers in response to various media amendments was reduced, which is in contrast to what is being advertised by various manufacturer. However, SAP only works efficiently in the non ionized water said by William J. Foster and Gary J. Keever, (1990) [45]. In an another experimental study by Nariman Babaee Sabzikar Langaroodi, Majid Ashouri, Hamid Reza Dorodian and Ebrahim Azarpour, (2013) [46] on the yield and yield component of the plant irrigated by saline water and using SAP conclude no significant benefits, work carried out by Hossein Bagheri and Peyman Afrasiab, (2013) [47] suggest that Salinity in the irrigation water also increases bulk density, decreases porosity and hydraulic conductivity as there is a less scope of water absorption in an ionic water medium and consequently SAP should not be used with saline water.

X. APPLICATION RATE OF THE SAP

Considering the above discussion it can be imagined that more the SAP mixed in the soil, more would be the water retention and improved soil moisture. To justify the cost of SAP material and to achieve benefit cost ratio in irrigation practice; optimum quantity of the SAP would required to be understood. Various studies have suggested to use SAP in different proportion basically depending upon the type of soil structure and other properties of soil, type of atmospheric condition under which it is being practiced, type of crop to be irrigated and mostly the quality of irrigation water to be utilized for the irrigation. Various researcher have suggested different rate of SAP to be applied as soil conditioner are listed in the following table – 1,

Sr. No.	Name of the Researcher	Suggested dosage of SAP	Recommendation for usage
1	S. Shooshtarian, J. Abedi-Kupai and A. TehraniFar,(2011)[35]	4 to 6 gram/kg of soil	For arid and semi arid region
2	Hossein Nazarli, Mohammad Reza Zardashti, Reza Darvishzadeh, Solmaz Najafi,(2010) [33]	2.25 to 3 gram/kg of soil	For all level of water stress treatment and improved irrigation period
3	Altarawneh, A., Kreuzig, R., Batarseh M., Bahadir M.,(2012) [48]	0.2, 0.4 and 0.8% of soil	To delay permanent wilting point in sandy soil
4	O.A. El-Hady and Sh.A. Wanas,(2006) [43]	2 to 4gram/plant pit	To save irrigation water is up to 15 to 50%
5	Liyuan Yan and Yan Shi,(2013) [31]	0.5 to 2.0 gram/pot	To improve relative water content and increased leaf water use efficiency
6	Leila Keshavars, Hasan Farahbakhsh and Pooran Golkar, (2012) [38]	0.2% to 0.4% (g/kg)	To moderate the negative effects of drought stress
7	H. Nazarli, M.R. Zardashti, R. Darvishzadeh and M. Mohammadi, (2011) [37]	225 to 300 kg/ha	To prohibit the bad effects of drought stress
8	Atiyeh Oraee and Ebrahim Ganji Moghadam, (2013) [36]	3%	To decrease water stress

Table – 1, Suggested application rates of SAP under different conditions

CONCLUSION

Uncertainty of rainfall, increased temperature in arid and semi arid regions is prominent throughout the world which encourages efficient water conservative irrigation technology of SAP. The technique has a great water absorption capacity by its own weight which helps in improving soil moisture capacity and hence reduces water stress on the plant during prolonged drought stress condition and during irrigation intervals. Quantity of total water required for the irrigation is also reduced by 15 to 50% when the soil conditioning by SAP in different proportion is adopted. SAP is safe, bio degradable, non toxic and inert with increased self life and lasts for years (10 to 15% degradation/year is observed) in the soil actively. Moreover, better aeration (exhausting of Carbon Dioxide and ingestion of Oxygen) in the root zone enhances germination, root development and microbial activities. Reduced use of fertilizers and pesticides adds to the overall benefits and the quality of yield. Further experimental investigation ought to be carried out to study the use of SAP to optimize the yield of cash crops to improve the economic and in turn social conditions of small and marginal farmers. Application rate of SAP requires to be analysed considering the quality of soil, water and type of crop to be irrigated. SAP is not best practiced in the regions which are irrigated with ionized water and hence the use of SAP in such regions can be optimized only using rain water harvesting techniques for small scale irrigation. This technology is widely unheard of to the farmers due to various reasons and therefore calls for special attention. Availability of agricultural SAP from the market is difficult for the ordinary farmers. The challenges are numerous but adoption of such an efficient innovative technology for the sustainable irrigated agriculture should be part of long term water management programme being under taken by various agencies. Govt. action plans, NGO's, agricultural research institutes and practical education programme to educate farmers regarding this technology could serve the purpose.

REFERENCES

[1] Rosegrant, W. Mark, Water Resources in the Twenty-First Century: Challenges and Implications for Action, Food and Agriculture, and the Environment Discussion Paper 20, International Food Policy Research Institute, Washington D.C., U.S.A, 1997
[2] Biswas, A. K, "Water for Sustainable Development in the Twenty-First Century: A Global Perspective", in Biswas, A. K.; M. Jellali and G. Stout (Eds.), Water for Sustainable Development in the 21st Century, Water Resources Management Series: 1, Oxford University Press, Delhi, 1993
[3] Biswas, A. K., "Water Policies in Developing World", Water Resources Development, Vol. 17, No. 4, pp. 489-499, 2001
[4] Saleth, R. Maria., Water Institutions in India: Economics, Law and Policy, Commonwealth Publishers, New Delhi, 1996
[5] CWC, Water and Related Statistics, Ministry of Water Resources, Central Water Commission (CWC), Government of India, New Delhi, 1996; 1998; 2002 and 2004
[6] MOWR, Report of the Working Group on Water Availability for Use, National Commission for Integrated Water Resources Development Plan, Ministry of Water Resources, Government of India, New Delhi, 1999
[7] Iyer, Ramasamy, R., Water: Perspectives, Issues, Concerns, Sage Publications, New Delhi, 2003
[8] INCID., Drip Irrigation in India, Indian National Committee on Irrigation and Drainage, New Delhi, 1994
[9] T.B.S. Rajput and Neelam Patel, MICRO IRRIGATION IN INDIA – PRESENT STATUS AND FUTURE SCOPE, India Water Week 2012 – Water, Energy and Food Security: Call for Solutions, 10-14, 2012
[10] Dr. K. T. Chandy, Agricultural & Environmental Education, Methods of Irrigation Booklet No. 57, Irrigation and Drainage: IDS – 15 Website: www.inseda.org/Agriculture%20and%20Environment%20Education
[11] S.Mahendra Dev, Small Farmers in India: Challenges and Opportunities, Indira Gandhi Institute of Development Research, Mumbai, 2012
[12] Ahmed A.: Applications of Functionalized polymers in agriculture; J. of Islam. Acad. Sci., 3(1): 49-61, 1990
[13] L. O. Ekebafe et al., Polymer Applications in Agriculture, Nigerian Society for Experimental Biology, Vol. 23, No. 2, June 30, 2011, pages 81 – 89, 2011
[14] Mohammad J. Zohuriaan-Mehr and Kourosh Kabiri, Superabsorbent Polymer Materials: A Review, Iranian Polymer Journal 17 (6), 2008, 451-477. , 2008
[15] Waham Ashaier Laftah, Shahrir Hashim, and Akos N. Ibrahim, Polymer Hydrogels: A Review, Polymer-Plastics Technology and Engineering, 50: 1475–1486, 2011
[16] Francesco Puoci, Francesca Iemma, Umile Gianfranco Spizzirri, Giuseppe Cirillo, Manuela Curcio and Nevio Picci, American Journal of Agricultural and Biological Sciences 3 (1): 299-314, 2008
[17] Mark Elliott, BASF Aktiengesellschaft, pp.12-13, 2010
[18] Prof.Feng Jin-Cheng and Prof. Ji Jing-Qiu, Root Irrigation with Super Absorbent Polymers-A New EffectiveWater-Saving Technique and Its Application,Qiong University, 572200, Wuzhishan, Hainan Province, China Website: www.watertech.cn/english/Root%20Irri.pdf
[19] Texas Department of Transportation, TxDOT's Guide to Roadside Vegetation Establishment, Website: http://onlinemanuals.txdot.gov/txdotmanuals/veg/index.htm., Accessed August 2013
[20] Fonteno, W. C., and Bilderback, T. E., Impact of Hydrogel on Physical Properties of Course- Structured Horticultural Substrates, Journal American Society of Horticultural Sciences 118: pp. 217-222, 1993
[21] Morante, J., Scientific Programme, European Biophysics Journal. Volume 38, Supplement 1, 2009

[22] Soler-Rovira, J., Usano-Martinez, M. C., Fuentes-Prieto I., Arroyo-Sanz, J. M., and Gonzalez-Torres, F., Retention and Availability of Water of Different Soils Amended with Super absorbent Hydrogels, Symposium SOPHYWA 6, 2006

[23] Koupai, J. A., Eslamian, S. S., and Kazemi, J. A., "Enhancing the available water content in unsaturated soil zone using hydrogel, to improve plant growth indices", Ecohydrology and hydrobiology, 8(1): pp. 67-75, 2008

[24] Abd El-Rehim, H. A., Hegazy, E. S. A., and Abd El-Mohdy, H. L., "Radiation Synthesis of Hydrogels to Enhance Sandy Soils Water Retention and Increase Plant Performance", Journal of Applied Polymer Science 93: pp. 1360-1371, 2004

[25] Fidelia Nnadi and Chris Brave, Environmentally friendly superabsorbent polymers for water conservation in agricultural lands, Journal of Soil Science and Environmental Management Vol. 2(7), pp. 206-211, 2011

[26] M. Yangyuoru1, E. Boateng, S.G.K. Adiku , D. Acquah1, T.A. Adjadeh and F. Mawunya1, Effects of Natural and Synthetic Soil Conditioners on Soil Moisture Retention and Maize Yield, West Africa Journal of Applied Ecology (WAJAE) –ISSN: 0855-4307, 2006

[27] W. Bai, H. Zhang, B. Liu, Y. Wu & J. Song, Effects of super-absorbent polymers on the physical and chemical properties of soil following different wetting and drying cycles, Soil Use and Management, 26, 253–260, 2010

[28] Yuguo Han , Xinxiao Yu, Peiling Yang, Bo Li, Lei Xu and Chengzhi Wang, Dynamic study on water diffusivity of soil with super-absorbent polymer application, Environ Earth Science,69:289–296 , 2013

[29] Martin Makgose Maboko, Thesis, Growth, yield and quality of tomatoes and lettuce as affected by gel polymer soil amendment and irrigation management, University of Pretoria, pp. 67-68 , 2006

[30] Bakass M, Mokhlisse A, Lallemant M, Absorption and desorption of liquid water by a Superabsorbent polymer: Effect of polymer in the drying of the soil and the quality of certain plants, J. Appl. Polym. Sci., 83: 234-243, 2002

[31] Liyuan Yan and Yan Shi, Effects of Super Absorbent Resin on Leaf Water Use Efficiency and Yield in Dry-land Wheat, Advance Journal of Food Science and Technology 5(6): 661-664, 2013

[32] Abd EI-Rehirn HA, Hegazy ESA, Abd El- Mohdy HL, Radiation synthesis of hydrogels to enhance sandy soils water retention and increase performance, J. Appl. Polym. Sci., 93: 1360-1371, 2004

[33] Hossein NAZARLI, Mohammad Reza ZARDASHTI, Reza DARVISHZADEH, Solmaz NAJAFI, The Effect of Water Stress and Polymer on Water Use Efficiency, Yield and several Morphological Traits of Sunflower under Greenhouse Condition,Print ISSN 2067-3205; Electronic 2067-3264, Not Sci Biol 2 (4), 53-58, 2010

[34] Alessandro Sannino, Application of Superabsorbent Hydrogels for The Optimization of Water Resources in Agriculture, The 3rd International Conference on Water Resources and Arid Environments (2008) and the 1st Arab Water Forum, 2008

[35] S. Shooshtarian, J. Abedi-Kupai, A. TehraniFar, Evaluation of Application of Superabsorbent Polymers in Green Space of Arid and Semi-Arid Regions with emphasis on Iran, Journal of Biodiversity and Ecological Sciences,No.1,Issue4,ISSN:2008-9287, 2011

[36] Atiyeh Oraee and Ebrahim Ganji Moghadam, The effect of different levels of irrigation with superabsorbent (S.A.P) treatment on growth and development of Myrobalan (Prunus cerasifera) seedling, African Journal of Agricultural Research, Vol. 8(17), pp. 1813-1816., 2013

[37] H. Nazarli, M.R. Zardashti, R. Darvishzadeh and M. Mohammadi, Change in activity of antioxidative enzymes in young leaves of sunflower (Helianthus annuus L.) by application of super absorbent synthetic polymers under drought stress condition, African Journal of Crop Science, AJCS 5(11):1334-1338 , 2011

[38] Leila Keshavars, Hasan Farahbakhsh and Pooran Golkar, The Effects of Drought Stress and Super Absorbent Polymer on Morphphysiological Traits of Pear millet (Pennisetum glaucum), International Research Journal of Applied and Basic Sciences. Vol., 3 (1), 148-154, 2012

[39] H. Nazarli, F. Faraji and M.R. Zarsashti, Effect Of Drought Stress and Polymer on Osmotic adjustment and Photosynthetic Pigments of Sunflower , Cercetări Agronomice în Moldova, Vol. XLIV, No. 1 (145), 2011

[40] H.R.Tohidi, A.H.Shirani-Rad, G.Nour-Mohammadi, D.Habibi and M.Marshhadi-Akbar-Boojar, Effect of Super Absorbent Application on Antioxidant Enzyme Activities in Canola (Brassica Napus L.) Cultivars under Water Stress Conditions, American Journal of Agricultual and Biological Sciences 4(3), 215-223, 2009

[41] Javad Khalili Mahalleh, Hossein Heidari Sharif Abad, Gorban Nourmohammadi. Farrokh Darvish, Islam Majidi Haravan and Ebrahim Valizadegan, Effect Of Superabsorbent Polymer (Tarawat A200) On Forage Yield and Qualitative Characters In Corn Under Deficit Irrigation Condition In Khoy Zone (Northwest Of Iran), Advances in Environmental Biology, 5(9): 2579-2587, 2011

[42] M. Robiul Islam, Xuzhang Xue, Sishuai Mao, Xingbao Zhao, A. Egrinya Eneji and Yuegao Hu, African Journal of Biotechnology Vol. 10(24), pp. 4887-4894, 2011

[43] O.A. El-Hady and Sh.A. Wanas, Water and Fertilizer Use Efficiency by Cucumber Grown under Stress on Sandy Soil Treated with Acrylamide Hydrogels, Journal of Applied Sciences Research, 2(12): 1293-1297, 2006

[44] Fidelia N. Nnadi, Super Absorbent Polymer (SAP) and Irrigation Water Conservation, Irrigation & Drainage Systems Engineering, Nnadi, Irrigat Drainage Sys Eng 1:1, 2012
Website: http://dx.doi.org/10.4172/2168-9768.1000e102

[45] William J. Foster and Gary J. Keever, Water Absorption of Hydrophylic Polymers (Hydrogels) Reduced by Media Amendments, J. Environ. Hort. 8(3):113-114, 1990

[46] Nariman Babaee Sabzikar Langaroodi, Majid Ashouri, Hamid Reza Dorodian and Ebrahim Azarpour, Study effects of super absorbent application, saline water and irrigation management on yield and yield components of peanut (Arachis hypogaea L.), Scholars Research Library, Annals of Biological Research, 2013, 4 (1):160-169, 2013

[47] Hossein Bagheri and Peyman Afrasiab, The effects of super-absorbent, vermicompost and different levels of irrigation water salinity on soil saturated hydraulic conductivity and Porosity and Bulk density, International Research Journal of Applied and Basic Sciences, ISSN 2251-838X / Vol, 4 (8): 2381-2388., 2013

[48] Altarawneh, A., Kreuzig, R., Batarseh, M., Bahadir, M., Impacts of Soil Amended Superabsorbent Polymers on the Efficiency of Irrigation Measures in Jordanian Agriculture, The 4th International Congress Eurosoil, Bari, Italy, 2012