International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4, 2025
https://www.theaspd.com/ijes.php

Hydrogel Polymer: A Water Conservation Practice For Drought Prone Agriculture

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1. Introduction:

The most crucial sector of the world economy is agriculture [1]. Nearly 1.3 billion people (About 40% of world) relying on agriculture. Drought has a dire impact on agriculture. Drought disrupts plant growth, resulting in a decrease in crop quantity and quality [2]. Application of water directly to the crop surface is a frequent irrigation method; however, it does not solve the drought problem [3]. Further, a large amount of water is wasted due to evaporation or runoff, and plants take in too little water, resulting in lower yields [4]. Sprinklers are an alternative method to reduce water waste but necessitate the purchase of costly equipment that most farmers cannot afford [5]. With a limited supply of freshwater and arable land, and an expected increase in global population of 9 billion by 2050, and 11.2 billion by 2100, [6], Food production must be tripled to provide enough food by increasing the yields of various crops both vertically and horizontally, and to reduce the gap between food crop production and consumption. There is a growing focus on producing enough food to feed each of us using every technology available. The need for water is constantly increasing in the current global ecological and economic scenario, yet the availability of clean water is decreasing [7]. Drought impact on farming is a worldwide issue that has prompted experts to seek novel solutions [8]. Drought cannot be stopped, but due to the growing availability of technological innovation, it can be forecasted. In some cases, hydrogel polymers having good water absorption capacity and retention capabilities even at high temperatures are one of the interim solutions [9]. Hydrogels improve soil physical properties by increasing water retention capacity, increasing infiltration and reducing irrigation frequency [10]. Cross linked polyacrylates or polyacrylamides are the most common hydrogel polymers employed in agriculture so far [11]. The inside of a hydrogel polymer is filled with water and buildup with a network of polymer chains. [12]. These structures may absorb and store rain water [13]. Using hydrogel polymers in soil allows water to be released slowly into the soil, allowing plant roots to absorb water more slowly, thus meeting their needs over a longer period of time [14]. Hydrogel polymers act as soil amendments to provide a suitable environment around plants when the root zone soil dries up, improving the efficiency of irrigation water and prolonging the duration of irrigation are both important in the field of agriculture. The dosage of hydrogel polymer must be adjusted according to the soil conditions [15].Based on sources, Hydrogel polymer may be natural or synthetic. Synthetic polymer hydrogels are not biodegradable, which hurts the environment [16]. Natural polymers (agarose, alginate, and chitosan) can be used to alleviate the problem of hydrogel structure deterioration. Irrigation using biopolymer hydrogels could be a solution to the current drought situation [17]. In the agricultural industry, hydrogel polymers are used for a variety of purposes, including water retention, seed coating, soil erosion reduction, food additives, tissue culture, and structural components (covers for agricultural products) [18]. According to previous studies, applying low concentrations of superabsorbent polymers (SAPs) to soil for physical properties such as aeration reduces the rate of agglomeration and association between soil particles [19], Therefore, the application of hydrogels may be the best technology to improve water and fertilizer efficiency in arid regions [20]. In this review, we discuss the role of hydrogel polymers in agriculture.

2. Hydrogel Polymer:

Hydrogel polymers are three-dimensional hydrophilic macromolecular components [21]. They are commonly used for drug delivery in medicine and as nutrient carriers for agricultural plants [22]. In comparison to their bulk, hydrogels can store a considerable amount of liquid by absorption [23], which can greatly boost their volume while avoiding the dissolving process. Water can be progressively released from this arrangement in a dry atmosphere. Hydrogels are curled up polymer bundles in their dry condition, which gradually relax and elongate when exposed to water [24]. When the absorption process is finished, the hydrogel reaches its maximal swelling and can no longer absorb any more water. Hydrogel polymers are inert materials that affect soil physical properties such as soil aggregates, soil permeability and water holding capacity, as well as soil density, structure, texture, and water release [25]. When the plant's root zone soil begins to dry out, the hydrogel polymer acts as a soil conditioner, retaining water and nutrients and returning them to the plant. These materials improve water use efficiency and watering intervals, increase soil water holding capacity by 2 to 4 times, and increase soil porosity. They also ensure proper root zone conditions by providing water and nutrients to plants, promoting plant vigor, root growth, and aeration [20], and also promoting seedling growth and reducing irrigation water volume, thereby extending irrigation intervals [26].

2.1. Hydrogel sensitivity to atmospheric conditions: As was previously noted, hydrogels are 3-D cross-linked hydrophilic networks that can reversibly expand and contract in a swollen state to absorb more liquid amount. Several physical and chemical factors may cause them to dramatically change their volume, where temperature, magnetic or electric field, pressure, light and sound considered as physical stimuli, while chemical stimuli includes pH, ionic strength, solvent composition and molecular species (Fig.1).

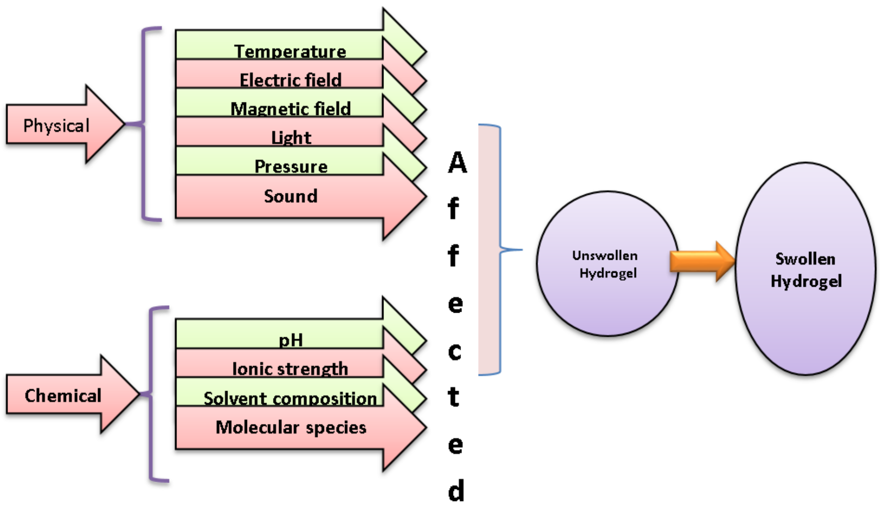

Fig.1:- Stimuli response for hydrogel swelling.

2.2. Hydrogel polymer water absorption and release mechanism: The process of water diffusion from polymer capsules is divided into numerous steps. Water in the soil solution migrates into the hydrogel due to rainfall [27]. The water inside the capsule builds up pressure, causing the water to slowly leak out into the soil [28]. The thickness and substance of the polymer covering are critical in controlled water release [29] (Fig.2).

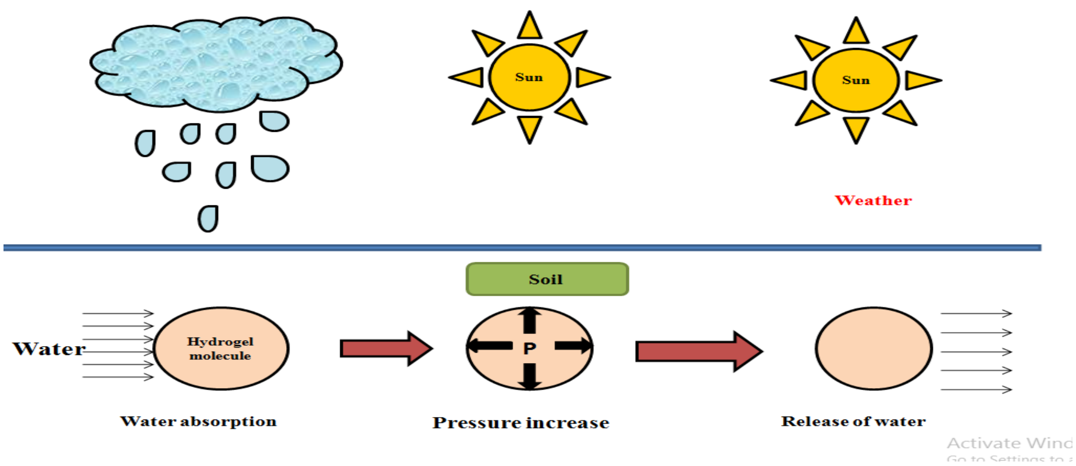

Fig.2:- Mechanism of water absorption and release.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4, 2025
https://www.theaspd.com/ijes.php

The capacity of hydrogel to absorb water amount is determined by two factors: first, the presence of a more carboxyl groups shown to bind to polymer side chains and can bind water molecules [30], and second, the polymer composition at the structural level and the appropriate porous structure [23].

3. Classification of hydrogel polymers:

By using various criteria, the hydrogel can be classified, as explained below (Fig.3):

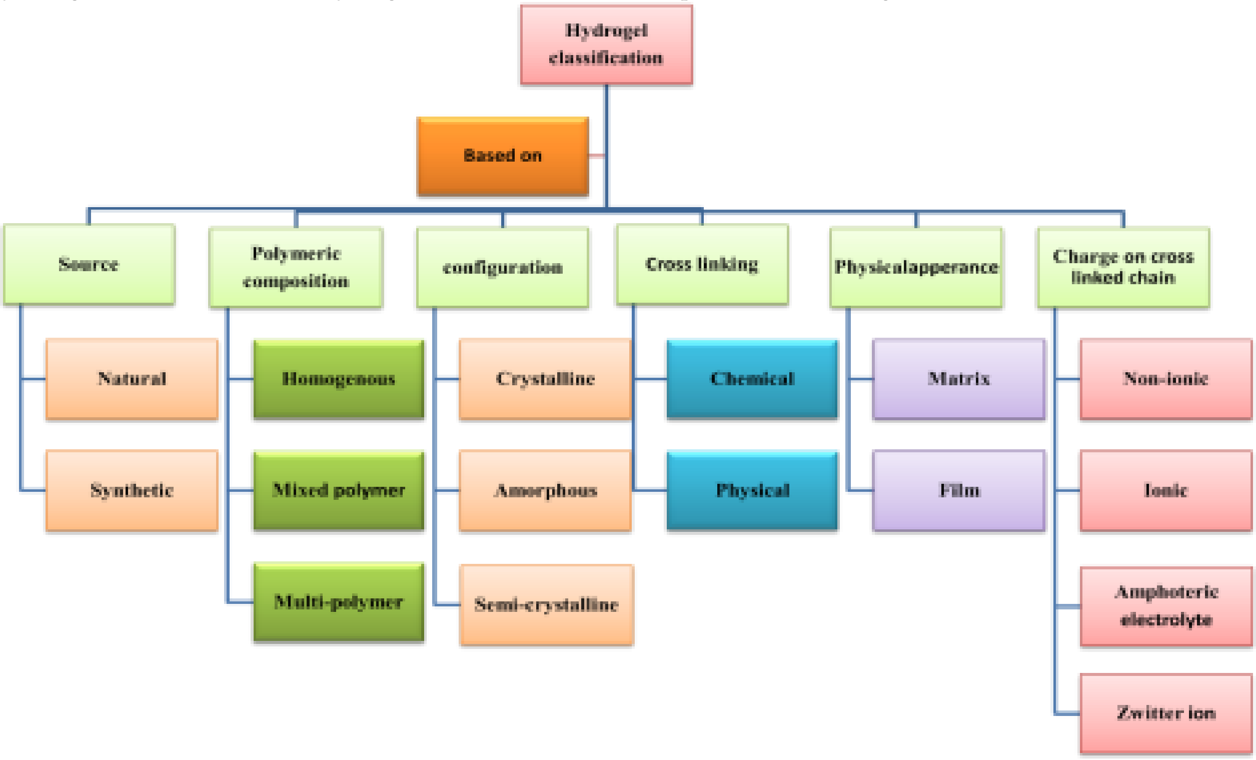

Fig.3:- Classification of Hydrogels.

(a) According to their Components/ source-based classification: Based on whether they are made of natural or artificial materials, hydrogels can be divided into two categories.

- Natural Polymers: These consist of natural plant components such as cellulose, starch, protein, rubber or animal products such as chitosan and gelatin, which are not harmful to the environment [31].
- Synthetic Polymers: Polymer molecules are linked together by gamma rays through covalent or ionic bonds [32].

(b) Depending on their polymeric composition: The preparation process results in the development of several significant hydrogel classes. The following are examples of these:

- Homogeneous Polymers: It is made up of only one type of hydrogel polymer chain [33].
- Mixed Polymers: It is made up of two or more types of copolymeric hydrogels [23].
- Multipolymer: This group of polymers [interpenetrating polymeric hydrogel (IPN)] made up of two or more types of natural and synthetic polymers in single compound [23].

(c) According to the configuration: According to their physical makeup and chemical content, classification of hydrogels as follows:

- Crystalline Polymers (Solid particles)
- Amorphous polymers (Liquid form).
- Semi-crystalline polymers (Glassy form) [34].

(d) According to their cross linking: According to whether the cross-link junctions are chemical or physical, hydrogel polymers are categorized into two groups. First, chemical cross linked networks, which have permanent linkages and second, physical networks have temporary connections created by physical interactions (ionic interactions, hydrogen bonding and hydrophobic bonds).

(e) Based on the physical appearance: In the preparation process, hydrogel polymer can take the form of a matrix or a film is depending on the polymerization technique.

(f) Based on the charge on the cross-linked chain: According to presence of charge on the cross-linked chains, hydrogel polymer can be seperated into various categories:

- Non-ionic.
- Ionic.
- Amphoteric.
- Zwitter ionic: Each structurally repeating unit contains both anionic and cationic groups.

4. Types of Hydrogel Polymers Used in Agriculture:

When the soil around the root Sdries, the various forms of hydrogel polymers absorb and store large amounts of nutrient and water, reaching upto 100 times of their original size, and provide nutrient and water to plants [20].

In agricultural field there are two main types of polymers are used as given below:

(a) Water soluble: This category of polymers comprises linear chains such as [35]:

- Polyethylene glycol.
- Polyacrylamide.
- Poly vinyl alcohol.
- Polyacrylates.

(b) Gel-forming: It is the most common variety in the farming sector; it is water insoluble and has been applied in agricultural sector since 1980s [19]. Hydrogel polymers hydrates to create an amorphous gelatin–like mass that can absorb and desorb for a lengthy period, when mixed with soil, thereby hydrogel acts as a water supplier inside the soil [17]. Change in water absorbability as well as the amount that can be released to the plant depending on the characteristics of their compositions; some polymers can reaching up to three hundred times their original weight, while others can absorb up to hundred times their volume of water in a short time period and providing high concentration of water to plants by releasing the absorbed water under dry conditions [36]. However, Super Absorption Polymer (SAP) is the important type of polymer used in agricultural sector because of their characteristics such as high absorbency and water retention. One gram of hydrogel polymer has capacity to absorb 400 and 500 ml of water. As a result, usage of SAP increases nutrient and water use efficiencies, also ameliorate seed germination rate and development of plant [37]. To protect seedlings from plant pathogens, increasing utilization efficiency and lowering production costs, various insecticides and slow-release fertilizers can be incorporated into polymers [38].

6.The salient features of hydrogel polymer: The following is a list of the functional characteristics of an ideal hydrogel material (Fig.4):

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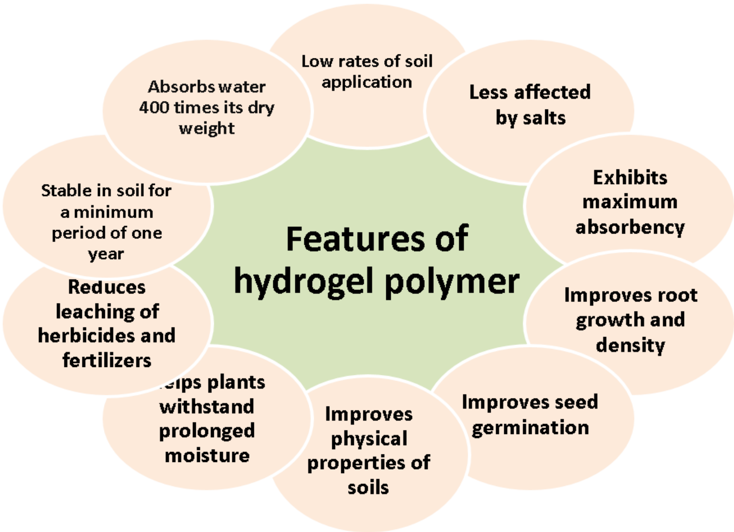

Fig.4:- Features of hydrogel polymer.

7. Characteristics of hydrogel polymer for agricultural applications: Following is a list of essential hydrogel properties for agriculture (Fig.5):

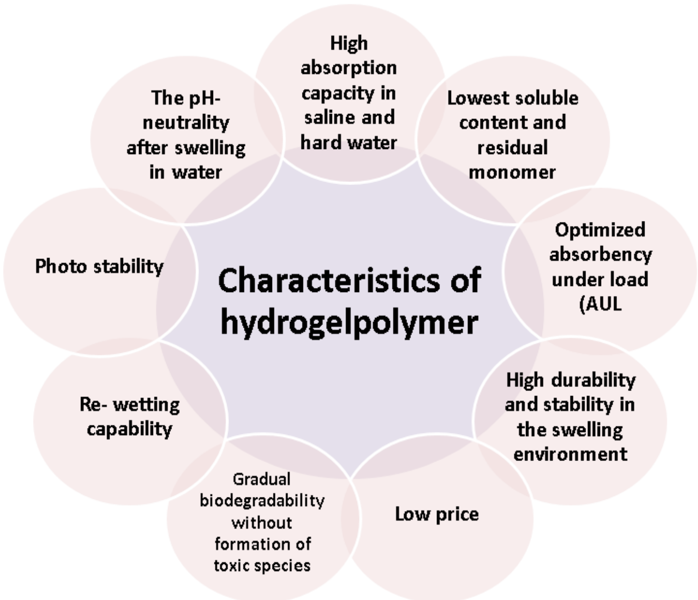

Fig.5:- Characteristics of hydrogel for applications in agriculture.

8. Advantages of Hydrogel Polymer in Agriculture:

Agricultural drought is defined as a combination of meteorological drought (related to a reduction in rainfall, and hence a reduction in soil moisture) and repercussions on agriculture [39]. Water consumption for plants varies according to the crops grown and the amount of space available [40]. Drought in agriculture considers the susceptibility of crops at various stages of development to negative drought factors [41], Reduced soil moisture, for example, will be more significant to plant development in the early stages of crop development than water scarcity and harvest. A lack of humidity during the growth of crops might lead to a reduction in productivity [42]. Due to its uses in various industries such as medicinal items, the cement industry, and agriculture, application of polymer is a very important topic in both practical and research fields [43]. Polymers are utilized for a variety of purposes in the agricultural industry, hydrogel used in soil conditioning, seed coating, fertilizers associated carrier, and pesticide and herbicide carriers [44]. In dry and semi-arid environments, hydrogel polymer acts as a structural material to create a climate that is favorable to plant growth [11, 17, 20]. Hydrogel polymer is used as retaining ingredient in various forms as shown below (Fig.6):

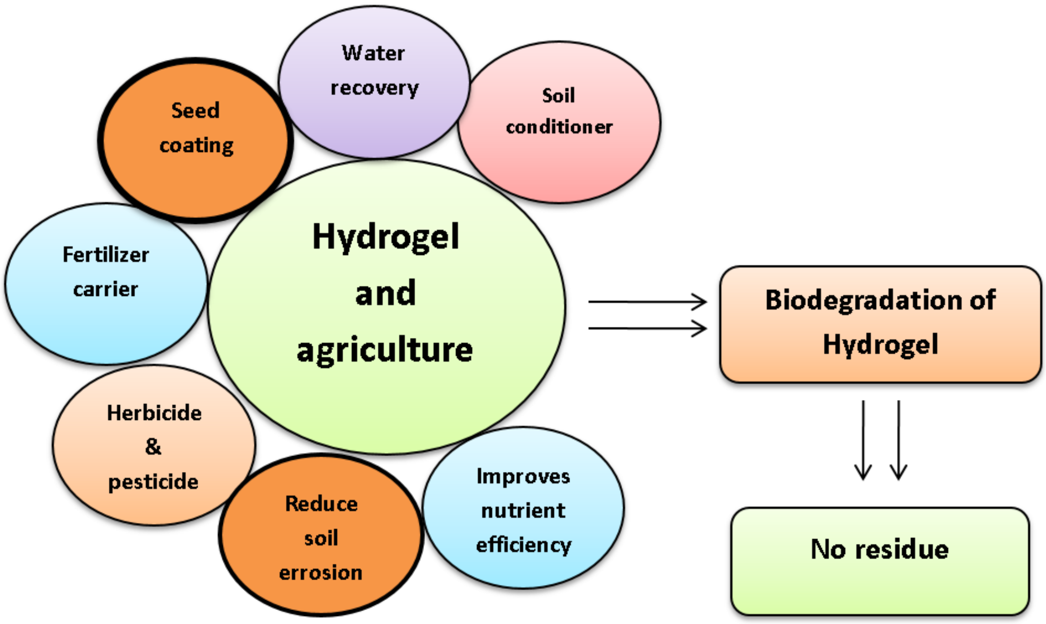

Fig.6:- Advantages of Hydrogel Polymer

9. Methods to use hydrogel polymer:

Polymer can be employed in many different ways depending on its cultivation type:

- New farm: Soil mixed with polymers is added to the farm before seeds sprout [20].
- Fruiting Orchard: Hydrogel is incorporated at the right depth into the soil on both sides of the trees [45].
- Field crop: Hydrogel polymers are applied in the planting furrows during soil preparation so that they are covered with soil and providing nutrient and water for the plants [44,46].
- Polymer spraying: In some circumstances, hydrogel polymers can be sprayed directly on the soil surface.

10. Hydrogel applications:

Plant growth and crop yields conceivably hampered by many factors, such as more transpiration rates, limited water retention capacity, high phytopathogen attack and soil moisture leaching [44]. As a result, agricultural use of hydrogel polymers may have the various advantages i.e. improves soil texture, water conservation, resistance to abiotic and biotic drought stress, reduced water consumption and irrigation frequency, decrease seedling mortality rate, and reduced excess use of pesticides and fertilizers in fields. Hydrogel polymer has been used in biological and agricultural applications in a few research studies. In order to satisfy the demands of increased production, a recent study was undertaken on a new superabsorbent named "Pusa Hydrogel," created by the ICAR (Indian Agricultural Research Institute New Delhi, India) [44,47]. Potassium polyacrylate is used for preparation of this new hydrogel polymer and at 50 degrees Celsius it shows maximum absorbency, which was particularly beneficial in arid and semi-arid soils [44,48]. Pusa Hydrogel was also found to be capable of absorbing water up to four hundred times its original weight, reducing herbicide and fertilizer leaking into the soil while also improving soil physical qualities [44,47]. In terms of plant growth, Pusa Hydrogel improved seedling emergence, seedling growth, root expension, and crop irrigation requirement and fertilizer demands [44,46,47]. This novel hydrogel, on the other hand, has no negative impacts on plants or soil [11,44,47]. The following are some of the hydrogel applications for boosting plant performance that was discussed in this review:

10.1 Soil Amendments:

Utilizing SAPs in the soil has a number of benefits, including the following in particular:

- By improving water and fertilizer retention quality, it increases soil aeration as well as reduced evapotranspiration [20,44].
- Impact on soil property likes its permeability, density, texture, structure, evaporation, and water infiltration rates [11, 20, 48].
- According to precise doses, it shows improvement of more than 50% in water retention capacity of soil [44].
- Soil implemented with hydrogel polymers have improved seedling germination and more water availability [17, 44].
- Soil texture can be changed by swollen hydrogel particles by changing the retention pores size and reducing drainage pore size. As a result, considerable decline in soil saturation and hydraulic conductivity is induced by inflated hydrogel polymer [44].
- Wet hydrogel polymers are particularly effective in blocking rainwater to create soil water reservoirs [44].
- Minimizing soil erosion and water runoff.

10.2 Drought Stress Reduction: Drought stress, which is caused by a unavailability of water in the soil, can result in the generation of free radicals and cell membrane damage by lipid peroxidation [49]. lipid peroxidation may have undesirable morphological consequences, like reduced leaf area, stunted height, and leaf damage. As a result, even in unfavorable environmental conditions, the application of hydrogels can improve growth and production. Hydrogel reduce the need of frequent watering so by this property it improves shelf life of container-grown plants [44]. Hydrogels have been found to have useful effects in horticulture, according to several studies, and their addition cause sudden increase in the water retention capacity [44,46] and enhance the water storage quality of porous soils, which is responsible for delaying in wilting periods. Turfgrass and bluegrass establishment and drought resistance was boosted in the greenhouse growing media as well in the field by Viterra 2 Hydrogel [44, 46,50].

10.3 Enhancement of Fertilizer Availability: Hydrogels are being used to reduce dependence on synthetic fertilizers for production without compromising crop production or nutritional value [11,48]. All these hydrogel properties are particularly useful for sustainable agriculture in semi-arid and arid environments [17, 44]. Potassium and nitrogen ions can also be added to hydrogels as fertilizer components [51]. For example, chemicals present in polymer networks cannot be immediately washable, but must slowly reach the soil and be utilized by the plants [44].On *Mimosa scabrella* seedlings, hydrogels mixed with several fertilizers based on conventional NPK, superphosphate and potassium chloride improved their growth due to increased water retention and nutrient uptake [44].

10.4 Seed Germination: No negative effects on seed germination were observed after hydrogel treatment [50, 52]. According to Ismail et al. [53], maize seeds treated with prepared superabsorbent hydrogels of acrylic acid and acrylamide had a good effect on maize seed germination and seedling growth compared to seeds without hydrogel [44]. Satisfactory effects on fresh and dry leaf and root weights were observed in hydrogel-treated plants [44]. Elshafie et al. [52] investigated the biological activity of oregano essential oil - based hydrogel formula and *Burkholderia gladioli* bacteria on *Phaseolus vulgaris* seed germination and observed that there is a highest significant seed germination in oregano essential oil - based hydrogel formula and *Burkholderia gladioli* bacteria.

10.5 Plant Growth: According to Macphail et al. [50], turfgrass and Baron Kentucky bluegrass were affected by various of hydrogels. They discovered that growth was unaffected at doses varies from 0 to 50 kg/100 m^2. According to Akhter et al. [54], use of hydrogel promoted plant development in certain species by improving water retention, particularly in regur soils [44, 55]. Konzen et al. [56] demonstrated that the application of hydrogel might similarly enhance collar diameter, fresh biomass, and plant height of *M. scabrella* seedlings under greenhouse environment. Filho et al. [57] investigated the best hydrogel dose for establishing *Enterolobium contortisilliquum* seedlings under 2^0 of brightness (50% and 100 %) and ten different hydrogel doses (0-6 g/L) and they found that the two doses i.e. 2 and 3 g/L, resulted in the best seedling growth in sunny as well as in shaded conditions. Bernardi et al. [58] found that stem diameter and plant height of *Corymbia citriodora* substrates increased 23 % by using 6 g/L hydrogel. Sarvas et al. [59], on the other hand, found that death of *Pinus sylvestris* plant takes place after treatment of 7g/L of hydrogel.

10.6 Yield attributes and yield: A great influence of Super absorbent polymer is observed on yield of cash crops in arid and semiarid locations, according to Dabhi et al. (60). According to Waly et al. (61), upland rice generated more grains/panicle, more grain yield and biological yield/pot, and the highest grain protein % by the use of 1% hydrogel. Pusa hydrogel, applied in furrow @ 2.5 kg/ ha during sugarcane planting, improved germination rate and crop vigor, leading to increased IWUE, cane return and CCS yield (62).

11. Important polymer safety precautions:
In fruiting orchards, to avoid damaging the tree's root system, the polymer should be applied in a circle around the tree, and it must be covered to shield it from the sun's heat [63]. Some other important precautions are listed below:

- Certain amount of moisture is required before adding of polymer in soil; so avoid adding of polymer into dry soil [64].
- Irrigation of the polymer immediately after application to activate it [19].
- Deciduous trees in an orchard: It is preferable to apply polymers during the dormancy/resting period.
- Field crop and Vegetables: To reduce the adverse impact of weather conditions, polymer is blended with soil, and covered after addition [19].

12. Hydrogel Biodegradability: Hydrogel are usually well fragile and efficiently assimilate into plant tissues [44]. Hydrogels, in contrast, are quickly destroyed after exposure to UV light. Polyacrylate, is highly susceptible to anaerobic and aerobic soil microbes, and is quickly decomposed into H_2O, CO_2, and N_2 compounds [44]. Hydrogels undergo process of mineralization as a result of biological degradation, such as that caused by fungi [44]. The biological breakdown of many types of polymers in the soil, in particular, is quite successful, especially under solubility conditions [44]. For instance, under aerobic conditions, hydrogel (Acrylate - based) biodegradation in municipal compost was achieved at a rate of 1- 9% /year comparable to that of decomposition of organic matter in the forest regions [44].

13. Drawbacks of Hydrogel in Agriculture:
The hydrogel's ability to absorb water is influenced by a variety of parameters, many of which limit its applicability in agriculture, as shown below:

- Water hardness has some bearing on how well the hydrogel absorbs water. The hydrogel's ability to absorb water is significantly diminished by the increased hardness brought on by rising Ca2+ and Mg2+ ion concentrations, which are mostly present in fertilizers and irrigation water sources. These magnesium ions interact with the polymeric chain of hydrogel at negative sites as it absorbs water, forming insoluble salts that block the ion sites. This obstruction worsens as a result of the water's increased salinity and additional soaking and drying cycles [65].
- The majority of soils have adequate water holding capacities for plant growth. If there is even a small amount of rainfall, water present in soil is exhausted therefore, hydrogel cannot solve the issue. Similar to that, it won't work at all under evenly distributed rainfall conditions [66].
- Usually, the hydrogel's price is excessively high, which makes it difficult to change the active rooting depth. Therefore, it can only be used to reduce irrigation frequency or reduce stress between irrigations in high-value crops, especially in cases when plant /crop value and quality are negatively impacted by drought stress.
- The effectiveness of hydrogel is highly affected by the nature of crop species, polymer type, timing and the method of application, and the soil texture. Typically, the polymers should be mixed into the soil at a proper depth, close to the root zone [67].
- Numerous studies have demonstrated that the hydrogel amendment to soil had little to no negative and positive effects on crop yield and moisture retention, respectively. When plants are under water stress, they can prefer to irreversibly take water from the biological system, which results in plant stands wilting.

14. Future trends for hydrogel polymer:

In the agricultural industry, the usage of hydrogel polymer has recently demonstrated remarkable potential and growth [11, 20], hydrogel polymer also drawing substantial interest in semiarid and arid locations to improve soil properties and crop yield [17, 20] . On the other hand, natural materials are now being used to obtain the majority of these materials for multifunctional applications, particularly in the field of slow-release nutrients [20].

15. Conclusion:

There is a surge in new inventive plant protection tactics being developed around the world in order to reduce reliance on pesticides (synthetic/chemical) while also protecting environment and living organisms [11,48]. Hydrogels have been effectively employed to improve plant performance and protect soil to face a variety of unfavorable environmental circumstances [17, 48]. The necessity of integrating SAPs and hydrogels for protection of seeds, soil, and plants has been underlined in the current review in [48]. As a result, using hydrogel-based natural agents to protect seeds and plants has yielded excellent results in terms of preserving soil fertility, minimizing water use, and reducing nutrient loss [17,48].

References:

(1) Cammalleri, C., Naumann, G., Mentaschi, L., Formetta, G., Forzieri, G., Gosling, S., ... & Feyen, L. (2020). Global warming and drought impacts in the EU. *Publications Office of the European Union: Luxembourg*.

(2) Idrees, M., Shahzad, N., & Afzal, F. (2022). Growing Climate Change Impacts on Hydrological Drought and Food Security in District Peshawar, Pakistan. In *Handbook of Climate Change Across the Food Supply Chain* (pp. 467-483). Springer, Cham.

(3) Ali, M. H., & Talukder, M. S. U. (2008). Increasing water productivity in crop production—A synthesis. *Agricultural water management*, *95*(11), 1201-1213.

(4) Leuthold, S. J., Salmeron, M., Wendroth, O., & Poffenbarger, H. (2021). Cover crops decrease maize yield variability in sloping landscapes through increased water during reproductive stages. *Field Crops Research*,*265*, 108111.

(5) Lefore, N., Giordano, M. A., Ringler, C., & Barron, J. (2019). Sustainable and equitable growth in farmer-led irrigation in Sub-Saharan Africa: what will it take?.*Water Alternatives*.

(6) Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision.

(7) Tzanakakis, V. A., Paranychianakis, N. V., & Angelakis, A. N. (2020). Water supply and water scarcity. *Water*, *12*(9), 2347.

(8) Van Loon, A. F. (2015). Hydrological drought explained. *Wiley Interdisciplinary Reviews: Water*, *2*(4), 359-392.

(9) Cheng, D., Liu, Y., Yang, G., & Zhang, A. (2018). Water-and fertilizer-integrated hydrogel derived from the polymerization of acrylic acid and urea as a slow-release N fertilizer and water retention in agriculture. *Journal of agricultural and food chemistry*, *66*(23), 5762-5769.

(10) Saha, A., Sekharan, S., & Manna, U. (2020). Superabsorbent hydrogel (SAH) as a soil amendment for drought management: A review. *Soil and Tillage Research*, *204*, 104736.

(11) Ekebafe, L. O., Ogbeifun, D. E., & Okieimen, F. E. (2011). Polymer applications in agriculture. *Biokemistri*, *23*(2).

(12) Laftah, W. A., Hashim, S., & Ibrahim, A. N. (2011). Polymer hydrogels: A review. *Polymer-Plastics Technology and Engineering*, *50*(14), 1475-1486.

(13) Aslan, D., & Selçuk, S. A. (2018). A Biomimetic approach to rainwater harvesting strategies through the use of buildings. *Eurasian Journal of Civil Engineering and Architecture*, *2*(1), 27-39.

(14) Mikula, K., Izydorczyk, G., Skrzypczak, D., Mironiuk, M., Moustakas, K., Witek-Krowiak, A., & Chojnacka, K. (2020). Controlled release micronutrient fertilizers for precision agriculture–A review. *Science of the Total Environment*, *712*, 136365.

(15) Landers, R., Hübner, U., Schmelzeisen, R., & Mülhaupt, R. (2002). Rapid prototyping of scaffolds derived from thermoreversible hydrogels and tailored for applications in tissue engineering. *Biomaterials*, *23*(23), 4437-4447.

(16) Dash, M., Chiellini, F., Ottenbrite, R. M., & Chiellini, E. (2011). Chitosan—A versatile semi-synthetic polymer in biomedical applications. *Progress in polymer science*, *36*(8), 981-1014.

(17) Singh, N., Agarwal, S., Jain, A., & Khan, S. (2021). 3-Dimensional cross linked hydrophilic polymeric network "hydrogels": An agriculture boom. *Agricultural Water Management*, *253*, 106939.
(18) Kasirajan, S., & Ngouajio, M. (2012). Polyethylene and biodegradable mulches for agricultural applications: a review. *Agronomy for sustainable development*, *32*(2), 501-529.
(19) Abobatta, W. F. (2019). Hydrogel Polymer: A New Tool for Improving Agricultural Production. *Academic Journal of Polymer Science*, *3*(2).
(20) Abobatta, W. (2018). Impact of hydrogel polymer in agricultural sector. *Adv. Agric. Environ. Sci. Open Access*, *1*(2), 59-64.
(21) Nguyen, K. T., & West, J. L. (2002). Photopolymerizable hydrogels for tissue engineering applications. *Biomaterials*, *23*(22), 4307-4314.
(22) Prasad, R., Kumar, V., & Prasad, K. S. (2014). Nanotechnology in sustainable agriculture: present concerns and future aspects. *African journal of Biotechnology*, *13*(6), 705-713.
(23) Ahmed, E. M. (2015). Hydrogel: Preparation, characterization, and applications: A review. *Journal of advanced research*, *6*(2), 105-121.
(24) Wang, S., Lu, A., & Zhang, L. (2016). Recent advances in regenerated cellulose materials. *Progress in Polymer Science*, *53*, 169-206.
(25) Zohuriaan-Mehr, M. J., Omidian, H., Doroudiani, S., & Kabiri, K. (2010). Advances in non-hygienic applications of superabsorbent hydrogel materials. *Journal of materials science*, *45*(21), 5711-5735.
(26) Salih, S. A., Abdulrahman, F. A., & Mahmood, Y. A. (2018). The effect of different irrigation interval on tuber yield and quality of potato (Solanum tuberosum L.). *Kurdistan Journal of Applied Research*, *3*(2), 27-31.
(27) Ojeda, T. (2013). Polymers and the Environment. *Polymer Science*, *23*.
(28) Skrzypczak, D., Mikula, K., Ligas, B., Widera, B., & Witek-Krowiak, A. Hydrogel composites as eco-friendly materials for water storage.
(29)Siepmann, F., Siepmann, J., Walther, M., MacRae, R. J., & Bodmeier, R. (2008). Polymer blends for controlled release coatings. *Journal of Controlled Release*, *125*(1), 1-15.
(30) Phadke, A., Zhang, C., Arman, B., Hsu, C. C., Mashelkar, R. A., Lele, A. K., ... & Varghese, S. (2012). Rapid self-healing hydrogels. *Proceedings of the National Academy of Sciences*, *109*(12), 4383-4388.
(31) Yu, L., Dean, K., & Li, L. (2006). Polymer blends and composites from renewable resources. *Progress in polymer science*, *31*(6), 576-602.
(32) Rezai, P., Wu, W. I., & Selvaganapathy, P. R. (2012). Microfabrication of polymers for bioMEMS. In *MEMS for Biomedical Applications* (pp. 3-45). Woodhead Publishing.
(33) Pande, P. P. (2017). Polymer hydrogels and their applications. *International Journal of Materials Science*, *12*(1), 11-14.
(34) Sharifpoor, S., & Amsden, B. (2007). In vitro release of a water-soluble agent from low viscosity biodegradable, injectable oligomers. *European Journal of Pharmaceutics and Biopharmaceutics*, *65*(3), 336-345.
(35) Sperling, L. H. (2012). *Interpenetrating polymer networks and related materials*. Springer Science & Business Media.
(36) Khodadadi Dehkordi, D. (2016). The Effects of Superabsorbent Polymers on Soils and Plants. *Pertanika Journal of Tropical Agricultural Science*, *39*(3).
(37) Islam, M. R., Hu, Y., Mao, S., Mao, J., Eneji, A. E., & Xue, X. (2011). Effectiveness of a water-saving super-absorbent polymer in soil water conservation for corn (Zea mays L.) based on eco-physiological parameters. *Journal of the Science of Food and Agriculture*, *91*(11), 1998-2005.
(38) Puoci, F., Iemma, F., Spizzirri, U. G., Cirillo, G., Curcio, M., & Picci, N. (2008). Polymer in agriculture: a review. *American Journal of Agricultural and Biological Sciences*, *3*(1), 299-314.
(39) Leng, G., Tang, Q., & Rayburg, S. (2015). Climate change impacts on meteorological, agricultural and hydrological droughts in China. *Global and Planetary Change*, *126*, 23-34.
(40) Condon, A. G., Richards, R. A., Rebetzke, G. J., & Farquhar, G. D. (2002). Improving intrinsic water-use efficiency and crop yield. *Crop science*, *42*(1), 122-131.
(41) Wilhelmi, O. V., & Wilhite, D. A. (2002). Assessing vulnerability to agricultural drought: a Nebraska case study. *Natural Hazards*, *25*(1), 37-58.

(42) Malhotra, S. K. (2017). Horticultural crops and climate change: A review. *Indian Journal of Agricultural Sciences*, *87*(1), 12-22.
(43) Ali, A., & Ahmed, S. (2018). Recent advances in edible polymer based hydrogels as a sustainable alternative to conventional polymers. *Journal of agricultural and food chemistry*, *66*(27), 6940-6967.
(44)Elshafie, H. S., & Camele, I. (2021). Applications of absorbent polymers for sustainable plant protection and crop yield. *Sustainability*, *13*(6), 3253.
(45) Huettermann, A., Orikiriza, L. J., & Agaba, H. (2009). Application of superabsorbent polymers for improving the ecological chemistry of degraded or polluted lands. *CLEAN–Soil, Air, Water*, *37*(7), 517-526.
(46) Nirmala, A., & Guvvali, T. (2019). Hydrogel/superabsorbent polymer for water and nutrient management in horticultural crops. *IJCS*, *7*(5), 787-795.
(47) Kalhapure, A., Kumar, R., Singh, V. P., & Pandey, D. S. (2016). Hydrogels: a boon for increasing agricultural productivity in water-stressed environment. *Current science*, 1773-1779.
(48) Neethu, T. M., Dubey, P. K., & Kaswala, A. R. (2018). Prospects and applications of hydrogel technology in agriculture. *Int. J. Curr. Microbiol. App. Sci*, *7*(5), 3155-3162.
(49) Fu, J., & Huang, B. (2001). Involvement of antioxidants and lipid peroxidation in the adaptation of two cool-season grasses to localized drought stress. *Environmental and Experimental Botany*, *45*(2), 105-114.
(50) MacPhail, J. M., Eggens, J. L., Harney, P. M., & Tsujita, M. J. (1980). Effect of Viterra 2 hydrogel on germination, seedling growth and sod establishment of Kentucky bluegrass. *Canadian Journal of Plant Science*, *60*(2), 665-668.
(51) Teodorescu, M., Lungu, A., & Stanescu, P. O. (2009). Preparation and properties of novel slow-release NPK agrochemical formulations based on poly (acrylic acid) hydrogels and liquid fertilizers. *Industrial & Engineering Chemistry Research*, *48*(14), 6527-6534.
(52) Elshafie, H. S., Nuzzaci, M., Logozzo, G., Gioia, T., & Camele, I. (2020). Biological investigations on the role of hydrogel formulations containing bioactive natural agents against some common phytopathogens of Phaseolus vulgaris L. and seed germination. *Journal of Biological Research-Bollettino della Società Italiana di Biologia Sperimentale*, *93*(2).
(53) Ismail, H., Irani, M., & Ahmad, Z. (2013). Starch-based hydrogels: present status and applications. *International Journal of Polymeric Materials and Polymeric Biomaterials*, *62*(7), 411-420.
(54) Akhter, J., Mahmood, K., Malik, K. A., Mardan, A., Ahmad, M., & Iqbal, M. 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 and Environment*, *50*(10), 463-469.
(55) Rehman, A., Ahmad, R., & Safdar, M. (2011). Effect of hydrogel on the performance of aerobic rice sown under different techniques. *Plant, Soil and Environment*, *57*(7), 321-325.
(56) Konzen, E. R., Navroski, M. C., Friederichs, G., Ferrari, L. H., Pereira, M. D. O., & Felippe, D. (2017). The use of hydrogel combined with appropriate substrate and fertilizer improve quality and growth performance of Mimosa scabrella Benth. seedlings. *Cerne*, *23*, 473-482.
(57) Pontes Filho, R. A., Gondim, F. A., & Costa, M. C. G. (2018). Seedling growth of tree species under doses of hydrogel and two levels of luminosity. *Revista Árvore*, *42*.
(58) Bernardi, M. R., Junior, M. S., Daniel, O., & Vitorino, A. C. T. (2012). Growth of seedlings of Corymbia citriodora as a function of hydrogel use and fertilization. *Cerne*, *18*(1), 67-74.
(59) Sarvaš, M., Pavlenda, P., & Takáčová, E. (2007). Effect of hydrogel application on survival and growth of pine seedlings in reclamations. *Journal of forest science*, *53*(5), 204-209.

(60) Dabhi, R., Bhatt, N., & Pandit, B. (2013). Superabsorbent polymersan innovative water saving technique for optimizing crop yield. *International Journal of Innovative Research in Science, Engineering and Technology*, *2*(10), 5333-5340.
(61) Waly, A., El-Karamany, M. F., Shaaban, A. M., Bakry, A. B., & 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*(2), 1018-1024.

(62) Singh, I., Verma, R. R., & 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*(1), 29-35.
(63) Asif, M. (2009). Sustainability of timber, wood and bamboo in construction. In *Sustainability of construction materials* (pp. 31-54). Woodhead Publishing.
(64) Willenborg, C. J., Gulden, R. H., Johnson, E. N., & Shirtliffe, S. J. (2004). Germination characteristics of polymer-coated canola (Brassica napus L.) seeds subjected to moisture stress at different temperatures. *Agronomy journal*, *96*(3), 786-791.
(65) Wu, Z., Meng, Z., Wu, Q., Zeng, D., Guo, Z., Yao, J., ... & Zhao, Y. (2020). Biomimetic and osteogenic 3D silk fibroin composite scaffolds with nano MgO and mineralized hydroxyapatite for bone regeneration. *Journal of tissue engineering*, *11*, 2041731420967791.
(66) Wu, Z., Meng, Z., Wu, Q., Zeng, D., Guo, Z., Yao, J., ... & Zhao, Y. (2020). Biomimetic and osteogenic 3D silk fibroin composite scaffolds with nano MgO and mineralized hydroxyapatite for bone regeneration. *Journal of tissue engineering*, *11*, 2041731420967791.
(67) Koupai, J. A., Eslamian, S. S., & Kazemi, J. A. (2008). Enhancing the available water content in unsaturated soil zone using hydrogel, to improve plant growth indices. *Ecohydrology & Hydrobiology*, *8*(1), 67-75.