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HYDROGELS: A REVOLUTIONARY MATERIAL FOR AGRICULTURE

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Abstract

Agricultural hydrogels are granules that hold the water and swell many times their original size when exposed to water. When there is a lot of rain or irrigation, it can absorb a lot of moisture and store it, then release it when there is a drought when the rhizosphere zone dries up to lessen crop water requirements. By forming connections with water molecules, the cross-linked super-absorbent polymer may absorb aqueous solutions. This innovative method of water management in water-stressed conditions lower losses through evaporation, deep percolation, runoff, and preserving crops' active rooting zones' soil moisture. The availability of soil water, which also has a significant impact on agricultural activity in regions with limited water resources, is crucial for the survival of both plants and the microbial community in the environment. It is used in agriculture for some things, such as retention of water in the soil pesticides and nutritional distribution, the grain's layer, reducing eroding soil, and as a nutrition ingredient. The comprises an amazing capacity to improve a variety of soil's physicochemical, hydro-physical, and biological properties while also lowering irrigation requirements, and enhancing nutrient and water use efficiency. It will be a benefit to include the hydrogel polymer workable and useful innovation instrument to boost agricultural yield under moisture-stressed conditions. Owing to the scant moisture and erratic temporal and geographic separation that severally threatens the viability of agriculture in the world's arid and semiarid regions, water shortage is a major environmental issue. The current approach to deficit watering innovation includes regarded as a crucial element in conditions of restricted water availability to preserve favorable higher water use efficiency with a balance of soil moisture in the root zone that doesn't affect crop production. By prohibiting the polymers from maintaining their capacity to release moisture and swell under moisture deficiency situations, enhancing plant growth and crop productivity in arid and semi-arid areas all around the world. They also prevent deep water evaporation loss extravasation, as well as dumping of vital nutrients. The development of hydrogels as controlled-release devices have seen a lot of scientific interest recently. The current study gives a brief overview of the numerous synthesis techniques, hydrogel types, and cross-linking agents that have been employed to create hydrogels with properties that are suited for agricultural applications.

KEYWORDS: Agriculture, Hydrogel, Fertilizers, Irrigation, Percolation, Soil moisture, Crop yield, Extravasation.

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1. INTRODUCTION:

The word ''hydrogel'' which is often used to describe ''water retention granules'', denotes an amorphous quasi-solid-phase substance[1][2]. This group of organic polymers has the extraordinary ability to quickly absorb a substantial moisture concentration into soil dries, these chemicals gradually release the held hydration to the adjacent root system and topsoil segment. When moisture shortage lasts for a longer period, water stress can be avoided by increasing the amount of water in the soil[3]. The hydrogel's capacity is because of the groups of functions that help they soak up wetness with hydrophilic properties connected polymer backbone, while its resiliency against dissolving is due to the cross-links between the network chains[4]. Synthetic and naturally occurring superabsorbent polymers are typically derived from petroleum sources. Synthetic polymers, on the other hand, have the unusual characteristic of exhibiting significant responsiveness to changes in the environment, including enlargement and contraction. Natural polysaccharide polymers are now prioritized above synthetic polymers due to controlled release methods, environmental safety, economic effectiveness, accessibility, and biodegradability. The polysaccharide with an abundance of hydroxyl groups can be used to create super-absorbent hydrogels with intriguing shapes and characteristics[3]. When compared to synthetic polymer hydrogels, polymer hydrogels derived from cellulose exhibit superior

Figure 1: Three primary forms of hydrogels suitable for usage in agriculture

Biocompatibility, great biodegradability, high strength, strong salt resistance, and high absorbency[5]. When used in soil, hydrogels hydrate to create an amorphous gelatinous material and can cycle through water absorption and loss for a longer time. Therefore, it is believed to be a good method for conserving enough although the environment surrounding the area where the crop roots are begins to dry eliminated substantial quantities of nourishment that are swiftly absorbed by the soil and are given to the plants gradually over an extended period [6]. The primary goal of this review's study has to ascertain the effectiveness of utilizing hydrogel on the soil's water retention and release capabilities will lessen the effects of drought while also increasing crop yields when moisture is scarce circumstances[7].

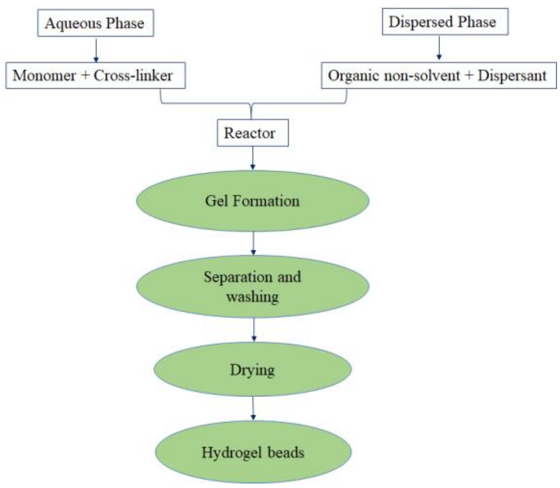

Figure 2: Formation of Hydrogel beads.

The use of hydrogels and agrochemicals together is a recent development in the field of hydrogel research since it allows for the management of nutrients and water using only one substance[8]. Even though they have been in agriculture. It has been determined that polyacrylic acid and polyacrylamide have a detrimental long-term impact on the natural world. Despite this, most of the hydrogels still used for farming purposes depend on these materials[9]. To make biodegradable and environmentally responsible hydrogels, a variety of biopolymers, including those produced from food such as protein and polysaccharides can be employed. A range of methods, including hot and cold sets, can be used to create casein hydrogels and casein-based hydrogels, which produce a variety of shapes[10]. The production of hydrogels that condition soil depends on their ability to absorb water and the rate at which it is released over time. Both the environment and the cross-linking density of the structure affect these factors. A quick, low-cost, and sustainable strategy to boost performance is to combine more biopolymers with hydrogels[10][11]. The features of polysaccharides, similar to each other variations in the composition of chemicals, the weight of molecules, associated biocompatibility, and lack of toxicity, make them attractive potentials among the existing biopolymers[12]. The positive outcomes previously attained when utilizing it for the encapsulation of substances with different bioactivities are what led to the selection of chitosan. When casein is combined with chitosan, it is possible to produce based on a water-resistant, gelatinous combination of ionic interactions, and hydrogen bonding along with actual chain interconnections[9]. As shown in earlier work with chitosan-casein complexes, low molecular weight molecules can often be contained within the structure of combined hydrogel molecules as opposed to those formed by just one element[13]. As urea is one of the most popular nitrogen-based fertilizers used in farming was chosen as a model fertilizer. Urea and microbial enzymes transform urea into ammonium and CO_2 when urea fertilizers are applied to the soil. The hydrolysis process can take a day or a week, depending on the temperature. Ammonium is converted to ammonia, which is discharged into the atmosphere when the soil temperature and pH are high. The conversion near the soil surface results in the greatest losses[14].

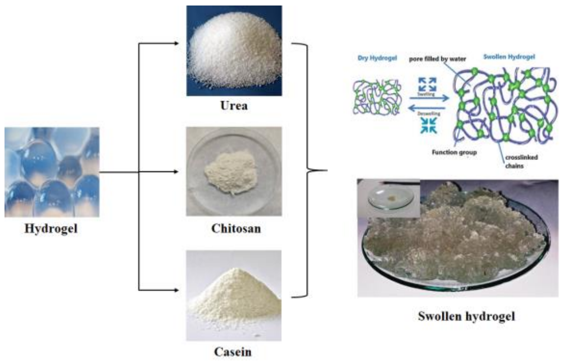

Figure 3: Composition and manufacturing process of hydrogels

2. HYDROGEL USAGE IN AGRICULTURE:

The essential component of the natural world for the continued existence of plants and the population of microbes is soil water availability, which also has a substantial impact on agricultural activity in areas with limited water supplies[15]. Effective handling of water techniques like micro irrigation with precise some of the technology advances employed sensibly in agriculture include controlling the amount of water in the soil and protecting growing plants from unfavorable shortages, planning for irrigation and alternate uses of soil enhancers such super absorbent polymers are recommended circumstances[16]. When placed in water or another aqueous solution, hydrogels, which resemble hydroscopic crystalline granules or microscopic beads and resemble white sugar, swell significantly and combine with other particles to form a clear gel. Synthetic polymers are produced through the polymerization of acrylic acid with a cross-linker[17]. Potassium polyacrylate is the key ingredient in hydrogel technology and the hydrogel available for use in agriculture. The amount and kind of cross-linker used has a significant impact on the gel modulus and swelling capacity. These are non-toxic, non-corrosive, and non-irritating in nature with an annual biodegradation rate of 10% to 15%. These polymers' ability to break down is influenced by their chemical composition[18].serving as seed coats for regulated seed germination, reservoirs for water as well as nutrients, soil conditioners to enhance the physical qualities of the soil, and more, as soil aerators, as soil sterilization agents, and to increase the water and chlorophyll content of leaves, hydrogels are widely used in arid and semiarid regions[19]. These polymers are frequently utilized in agriculture because of their capacity to hold more long-term irrigation of the soil over time furthermore, they allow plants to access nutrients and moisture gradually. In bad weather, they also serve as buffers against transitory drought stress, rescuing the chance of crop failure during crop establishment, encouraging plant growth and development, and achieving larger yields and higher-quality crops[20].

3. HYDROGEL APPLICATIONS FOR AGRICULTURE:

Here is a summary of how hydrogel is used in agriculture, along with proposed methods and advantages.

3.1 Reducing drought stress in agriculture using hydrogel: Oxygen radicals produced as a result of drought stress can promote lipid peroxidation and oxidative stress in plants. Stun height, a reduction in damage to the foliar structure, leaf region, etc. are all visible effects[21]. Hydrogel can lessen the effects of dryness lessening stress and oxygen radical generation on plants, with increased potential for proliferation and output regardless of unfavourable environmental circumstances[22].

3.2 Hydrogel polymer biodegradability in agriculture: Hydrogel is UV-sensitive and degrades into oligomers, according to studies[23]. The polyacrylate may transform into water, CO_2, and nitrogen compounds at rates of ten to fifteen percent every year, but it becomes much more susceptible to microbial degradation from both anaerobic environments because the water-soluble molecules have barely any chance for absorption because they are now too large to be assimilated by the tissues of plants[24].

3.3 Agriculture using hydrogels to converse agriculture lands: when properly amended with different soil-to-hydrogel ratios, the addition of hydrogel polymer can boost the soil's ability to retain water by 50-70%[25]. There may be an 8-10% reduction in soil bulk density over time. The soil's capillary permeability with water has been trending rising with an increase in hydrogel dosage, clearly indicating a gain in agricultural water usage efficiency in arid and semi-arid settings[26]. The net plant yield benefits from this. In contrast to the promotion of aeration and microbiological activity, irrigation frequency, compaction propensity, and runoffs decrease[27].

3.4 Enhanced fertilizer efficiency in agricultural hydrogels: fertilizer, herbicide, and germicide applications are severely hampered by irrigation technology. According to studies, hydrogel agriculture can significantly reduce the need for synthetic fertilizer without lowering crop production or nutritional value[28]. It would be a better suitable method for sustainable agriculture in areas with similar biological constraints and dry or semi-arid climates. Additionally, potassium polyacrylate is non-toxic and safe, preventing the polluting of agricultural ecosystems[29].

Table 1: A straightforward dose table has been provided here, the exact dosage and administration must be decided after testing the particular soils that need to be treated.

S. No.	Quantity of hydrogel	Kinds of soil	Reference
1	4.1 to 6g/kg	The semi-arid and arid region	[19]
2	2 to 3.5g/kg	Treatment of all levels of water stress and lengthened irrigation periods	[7][5]
3	0.2 to 0.45g/kg	To postpone the sandy soil's irreversible wilting point	[30][31]
4	2 to 4.5g/ plant pit	To cut back on the water by 50% in a loamy soil	[32]
5	0.5 to 2g/pot	To increase leaf water use efficiency and relative water content	[33]
6	0.2 to 0.45% of soil	To lessen the stress caused by drought	[4][7]
7	215 to 299kg/ha of cultivated area	To completely outlaw drought stress	[34]
8	4% by weight	Reduce water stress	[35]

4. EVALUATION OF pH SENSITIVITY AND CONSUMPTION OF WATER IN SOIL:

The performance of a hydrogel is significantly impacted by the pH of the soil, which has an impact on water absorption and swelling behaviour [36]. A chili crop's usual pH range is between 5.5 to 7 the amount of liquid absorbed by the substance up until saturation was used to test the hydrogel's ability to absorb water. In PBS solutions with a range of pH values from 5 to 7 and distilled water as the control[37]. After 24 hours, the swelling balance was attained. In all pH ranges, the equilibrium water content of the hydrogels was between 10.9 and 12 times their weight. There was no discernible difference, according to the statistical analysis[38]. The expansion of the hydrogel was caused by the degree of ionization these are the carboxylic and amine hydrogels and the development of freshly created bonds throughout the production process at different pH levels of hydrogels. The mechanism underlying the phenomena depends on the entry regarding particles of water entering the emulsifying framework, followed by the hydrogel's macromolecular hyperlink relaxing[39].

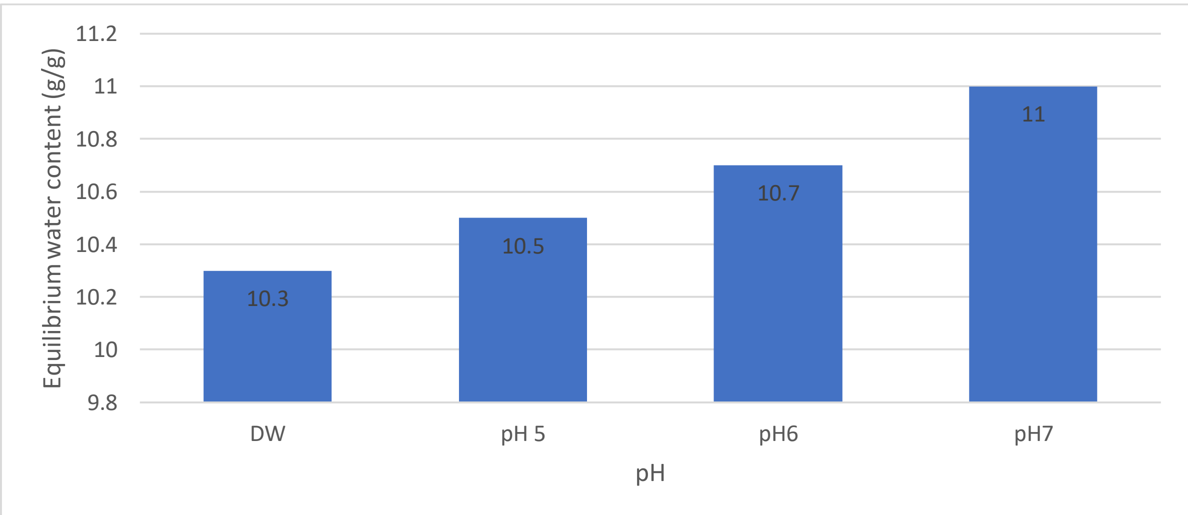

Figure 4: Ratios of hydrogel swelling at various pH levels.

5. NATURAL POLYMER BASES IN AGRICULTURE:

Agriculture utilizes the most water, and cutting back on water use creates several challenges. Polyesters, proteins, and polysaccharides are the three main types of natural polymers that can be distinguished by their structural properties[40]. Consequently, the focus of this chapter is on polysaccharide derivatives and how they can be coupled to create useful polysaccharide hydrogel composites, additional synthetic polymers are combined with top-notch properties for use in agriculture as a fertilizer and soil conditioners. Agricultural polysaccharide hydrogels, improve the soils to retain water and its porosity while also enhancing plant survival and overall food yield, creating an environment that is favorable for the growth of flora. The importance of polysaccharide hydrogels and their applications in the agriculture sector[41]. APH has been used as a fertilizer carrier and has demonstrated the gradual release of fertilizers and controlled-release fertilizers, which decrease the amount of fertilization required and are more affordable than conventional fertilizers. To be considered a smart fertilizer, CRFs should ideally release nutrients in response to changes in many factors. Additionally, ‘’Nano’’ fertilizers, which are easily speared and root diffused in all plants, are known as loaded fertilizers or those encapsulated by nanostructure biodegradable hydrogels[14]. These fertilizers increase crop production. In comparison to traditional fertilizers, ‘’smart’’ and ‘’Nano’’ fertilizers both offer benefits. The use of APHs as a plant defence against creatures such as insects, fungal and bacterial infections, and desiccation is currently being researched, as well as potential future effects[42].

6. AGRICULTURAL SOIL CONDITIONERS:

Superabsorbent hydrogels remain a major problem in both academic and industrial settings areas because they can be used with numerous innovations[43]. The tremendous quantity of papers and patents serves as evidence for this related to superabsorbent hydrogels that have been published[44]. In particular, those made of polysaccharides that serve as soil conditioners and polymers transporters for the release of nutrients are the focus, which aims to explore and update several important areas of the creation, evaluation, and use of superabsorbent for agricultural purposes[20][45]. The basic SH properties and these are several ways to change polysaccharides chemically also covered, in addition to showcasing alternative production directions for hydrogels. In light of some mathematical models, mechanisms for transferring water into the three-dimensional matrix are examined, when mass transport from the hydrogel-soil system to the plant is taken into account[46]. Even when the network is swollen, SH can maintain stability. Such features come as a result of the crosslinked structure, which ensures SH robustness in a variety of mediums and conditions. The two basic methods for crosslinking are chemical processes and physical methods[47]. The primary characteristic of the chemically crosslinked SH is the formation of irreversible covalent connections between the polymeric chains. A wide range of crosslinking techniques, including radical polymerization, complimentary group reactions, grafting processes, enzymes, etc., have been employed to generate chemical hydrogels[48][49]. In contrast, physical factors such as electrostatic interactions hold the polymeric chains physically crosslinked together[50]. It is without a doubt essential to characterize the water-absorbing capacity to comprehend the SH structure and prospective features. For investigations examining the production and characteristics of SH, swelling tests are essential. Such tests can be run in a diverse array of environments, over a wide range of periods, and with or without the inclusion of extraneous elements like light, a magnetic or electric field[51]. A complete explanation of the profile of oedema displayed by a particular SH guarantee improved application and appropriate reactions in particular circumstances[52]. The weak mechanical qualities of substantially swollen SH are a serious negative. The mechanical characteristics of hydrogel deteriorate as water content rises. The use of fillers as reinforcing agents is one of the most important developments in this sector. Some works are devoted to investigating methods to overcome[53]. Water molecules and the chemical groups that make up the SH networks is responsible for this intriguing property. These materials typically contain electrically charged groups, which, during the earliest stages of swelling, encourage electrostatic interactions with the water molecules. Hydrophobic moieties in the SH matrix molecules have occupied all the hydrophilic and hydrophobic spots. The 3D networks accessible vacant areas are all filled by the water molecules[54][55].

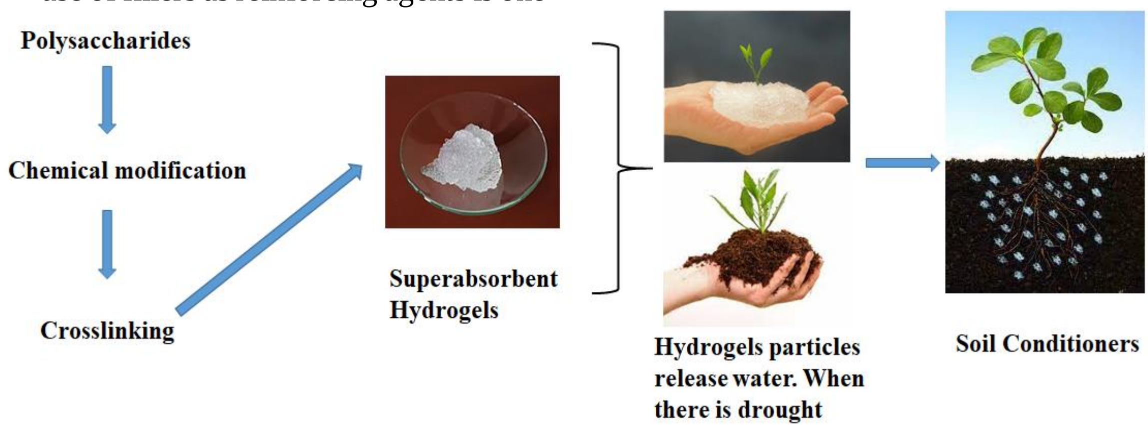

FIGURE 5: Graphical representation of agricultural soil conditioner composed of superabsorbent hydrogels based on polysaccharides.

7. HYDROGELS BASED ON CHITOSAN WITH POTENTIAL FOR SUSTAINABLE AGRICULTURAL USES:

Agriculture, despite being a substantial economic sector, uses a lot of water, a valuable and finite natural resource[56]. Crop growth, survival, and production are impacted by irrigation practices and water conservation initiatives. When used with fertilizers, superabsorbent polymers can result in a continuous release of nutrients and improved soil water retention[57][58]. Despite recent significant advancements in this sector made by synthetic poly acrylate hydrogels, neither naturally occurring biopolymers nor synthetic polymers enhanced with natural components have any commercially viable solutions displaying comparable performance. Hydrophilic crosslinked polymers also referred to as hydrogels, can absorb a lot of water without dissolving in it[59][60]. The polymer backbone's hydro groupings can absorb water, but the network chain crosslinks make dissolving resistance more difficult. Hydrogels are stable in a variety of situations due to their crosslinked structure, which allows them to maintain their network integrity when they swell[61][62]. Hydrogels made relative to the control material are often built relatively weakly crosslinked; as a result, they have a remarkable capacity for water absorption, which is much more than hydrogels formed from non-ionic monomers and extensively crosslinked[63][64][65]. Since they can hold onto water and nutrients and release them gradually over time, hydrogel materials are regarded as soil conditioners and yield enhancers. It is possible to match the hydrogel degradations rate of nutrient release to the plant's dietary needs. When applied as a coating on environmentally friendly fertilizers, hydrogels can increase the soil's ability to retain water[66][67]. Another form of agricultural material is a slow-release fertilizer hydrogel, which combines the benefits composed of a very absorbent viscoelastic as well as a fertilizer to enhance soil quality and boost fertilizer effectiveness. Superabsorbent hydrogels and fertilizers are being used more frequently to control fertilizers and water in one system[68].

8. AGRICULTURAL APPLICATIONS OF GUAR GUM-BASED HYDROGEL:

Recently, an orderly discharge of plant nutrients in soil has been examined using hydrogels that have been loaded with nutrients[69]. Given how quickly natural biopolymers-based hydrogels form. For the regulated release of nutrients in the soil, hydrogels with a combination of chemicals and inherent polysaccharides as fundamental elements were established and intensively researched and do not biodegrade[70]. Hydrogels release nutrients in harmony with the soil per the concentration gradients of the external medium, enabling plants to release nutrients based on their specific nutritional requirements. Additionally, by using controlled release, it is possible to maintain the ideal concentration of agrochemicals for a longer length of time and substantially reduce leaching losses[71][72]. One of these polysaccharides that is well-known for its versatility is guar gum. As we have previously mentioned, the superabsorbent hydrogel made by cross-linking ethylene glycol di methacrylate with acrylic acid and guar-gum during the grafting proves has shown significant promise as an enhanced soil and soil moisture retention tool[73]. For every gram of dry weight, this hydrogel displayed water absorption of up to 800ml significantly increasing the ability of sandy-clay-loam soil to retain water. The soil's porosity and water-holding capacity were both increased by this hydrogel by 54% to 9% respectively. By conducting soil burial biodegradation investigations, it was discovered that the synthetic hydrogel has a half-life of 77 days and is biodegradable[74]. There have been studies into controlled release techniques for nutrients from different matrices, however at present this writing, no results of their testing in comparison to a commercial fertilizer have been reported[75]. The research was started to fill in the information gap regarding the gradual release using natural hydrogel made of polymers in heavily drained soils that are acidic. Therefore, the purpose of this work is to create a controlled release mechanism on superabsorbent polymer to ensure its long-term availability in problematic soil[76].

9. FUTURE PERSPECTIVES:

The above-mentioned explanation makes it abundantly evident that hydrogels are extremely valuable in the agricultural sector, especially for the discharge of water and fertilizers, for increasing soil porosity, for improving seed emergence, and for seedling establishment. They offer a sustainable answer to agricultural issues, particularly those connected to water constraints. The moisture of the soil could be studied using a hydrogel-based sensor, which could be integrated with technology that would release water when an exceptionally inadequate moisture threshold occurs according to Demitri et al[77]. This is in addition to the typically utilized gel in horticulture Ali et al[11]. constructed a sensor of this kind by joining the hydrogel to the circuit. Hydrogel swelled in the presence of water, turning on the NFC switch, and via versa. To verify this circuit system's effectiveness at maintaining soil moisture, it might be connected to a soil system. However, certain qualities such as tolerance are taken into consideration to utilize hydrogels in agriculture to the fullest extent possible[15]. It is necessary to optimize the processes for creating and using hydrogels. In hydrogel formations, the use of potentially harmful cross-linkers or contaminated reagents must be completely avoided. The amount of hydrogels used in agriculture needs to be optimized for the type of soil and crop being used. The cost of creating hydrogels and using them on the market must be taken into account for farmers, availability is essential[78]. To make use of the affordable in addition to their sustainability, these naturally existing assets, the utilization of cellulose and other lignocellulosic derivatives for the synthesis of hydrogels and their use in agriculture. Even if it is difficult enabling an individual hydrogel to perform at the highest level in all practical applications, significant advancements in hydrogel-medicated sustainable agriculture will surely be seen as research and innovation continue. By lowering water use, boosting crop production, and promoting plant development, hydrogels have demonstrated considerable promise for better agricultural practices [52].

10. CONCLUSION:

According to this review, the development of crops that can be sustained in dry and semi-arid environments is increasingly being hindered by water. In addition to increasing the soil's ability to hold and release water, the hydrogel can be used to treat soil. Furthermore, it can increase crop yield and quality while enhancing irrigation effectiveness and the efficient utilization of nutrients and water. It might also improve the quality of the environment. By increasing yield and reducing soil moisture stress, this hydrogel technique may prove to be revolutionary and commercially valuable in locations with a shortage of water. They are being applied to problems with water scarcity, drought, and climate change, which are significant difficulties encountered by farmers all over the world. In large volumes of hydrogels, water can be absorbed and retained, which can help maintain soil moisture levels and lessen water loss from evaporation. As a result, water use may be significantly reduced, and crop output may rise. Additionally, hydrogels can boost soil aeration, nutrient availability, and soil structure, all of which can further improve plant development. Although the use of hydrogels in agriculture has produced encouraging results, there are still some worries about their long-term consequences on the health of the soil and the ecosystem. Understanding the advantages and restrictions of employing hydrogels in agriculture will require more research. Overall, hydrogels have the power to transform agriculture by offering an effective and long-lasting method of managing water in farming. The widespread use of hydrogel could benefit farmers and other stakeholders due to its beneficial effects on water resource management, which would boost agricultural productivity.

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