

Polymeric Hydrogels and their Applications in Agricultural Field: A Review

Amar Nath¹

¹Department of Chemistry, B.R.D.P.G. College, Deoria, UP, India -274001.

Publication Date: 2025/09/29

Abstract: Three dimensional cross-linked macromolecular structures of polymeric hydrogels (PHGs) that have more capability of absorbing and holding large amounts of water in comparison of their dry mass. Their outstanding water retaining potential and ability to controlled discharge of nutrients, agrochemicals, and bioactive compounds have attracted considerable interest in sustainable agriculture. This review illustrated about the structure, classification, synthesis, and applications in agricultural field. Their hydrophilic nature of polymeric materials has emphasis on their responsibility in soil conditioning, water management, fertilizer delivery, crop productivity, and microbial activity. The advantages, limitations, and future prospects of synthetic, natural, and hybrid hydrogels in agricultural systems are also discussed.

Keywords:- Hydrogels, Agrochemicals, Soil Conditioning, Sustainable Agriculture, Natural and Hybrid Hydrogels.

How to Cite: Amar Nath (2025) Polymeric Hydrogels and their Applications in Agricultural Field: A Review. *International Journal of Innovative Science and Research Technology*, 10(9), 1848-1855.
<https://doi.org/10.38124/ijisrt/25sep1158>

I. INTRODUCTION

The hydrophilic polymers having macromolecular materials have strong affinity toward water. When hydrogels are present in cross-linked into a three dimensional arrangement [1-3], they form hydrogels capable of absorbing up to 4000% of their dry weight in water and it maintained their structural stability under pressure. The availability of functional groups likes hydroxyl (–OH), amide (–CONH–, –CONH₂), sulfonic (–SO₃H), amine (–NH₂), and carboxyl (–COOH) [4] that contributes their water absorption and retention capacity. Owing to their insolubility in excess water and swelling ability, polymeric hydrogels (PHGs) have found diverse applications in agriculture [5].

This review summarizes the role of hydrophilic polymeric materials in crop production, soil improvement, and controlled delivery of agrochemicals [6]. Their advantages,

limitations, and practical challenges are addressed, alongside classification based on source and properties.

II. ADVANTAGES OF HYDROGELS IN AGRICULTURE [7]

Polymeric hydrogels shows a number of functional valuably about agricultural field:

A. Managing of Moisture

Polymeric hydrogels have superabsorbent potential that represent facilitate retention and gradual release of water in the rhizosphere shown in Figure1 [8].

B. Carrier Activity

Polymeric hydrogels encapsulate and deliver fertilizers, micronutrients, stimulants, and pesticides in a proper manner. Some hydrogels and their functions are given in Table 1[6].

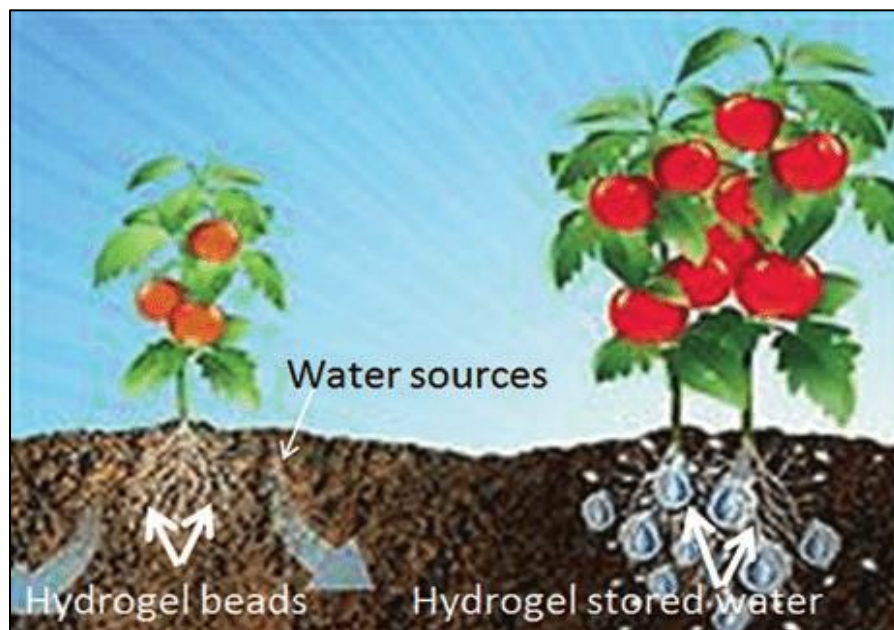


Fig. 1- Conditioning of Soil with Hydrogel.

C. Conditioning of Soil

Hydrogels are improved their physical, chemical, and biological soil properties, increase fertility, and it act as localized water basin. It gradually released absorbed water to soil that maintained moisture and helped to the crop and plants. That provides water and helped in development of plants that is why it benefits to the arid region vegetations [6].

D. Performance Towards Plant

The hydrogels holding capacity helped into the improving of soil ventilation, root propagation, and water delivery, they encourage higher rates of germination, vegetation survival, and productivity; in due course reduce the costs cultivation [6].

E. Prevention of Soil Erosion and Landscaping

The water retention capacity of polymeric hydrogels can be used in arid regions, urban landscaping and kitchen gardens. In which hydrogels where they mitigate soil erosion and increase seedling of crop in agricultural field. [9].

F. Cultivation in Soilless Region

Due to their structural network it facilitates the holding capacity so that it feasible to used in hydroponics and sandy area. At this position insufficient fertile soil are present. Use of hydrogel enhanced the farming of sea and ponds.

G. Sustainability of Nutrient Release

Hydrogels have encapsulation capability towards the various substances like fertilizer, nutrients, micronutrients and other agrochemicals. Due to the encapsulation ability of hydrogels it released fertilizers gradually and maintained the long time soil fertility.

III. CLASSIFICATION OF HYDROGELS [10]

A. Based on Source

➤ Synthetic Hydrogels

These classes of hydrogels were synthesized in laboratory and these are also known as artificial hydrogels. It can be synthesized by using petrochemical monomers like acrylamide and acrylic acid. They have high swelling potential, mechanically strong and more stable. While these hydrogels does biodegradable and it also shows non eco-friendly in nature.

➤ Natural Hydrogels

This type of hydrogel obtained from biopolymers including cellulose, starch, alginate, chitosan, and guar gum etc which are renewable, eco-friendly, biodegradable in nature. But these hydrogels have mechanical low stability and also have low swelling and water retention capacity.

➤ Hybrid or Semi-Synthetic Hydrogels

Such classes of polymeric hydrogels are called as copolymer. These hydrogels are the combination of both synthetic and naturally occurring monomers. These hydrogels are eco friendly, easy to naturally degrade, mechanically robust. So that these hydrogels are make the alternative use in agriculture field.

B. Synthetic Hydrogels [10]

There are two class of synthetic hydrogel found which are based on the monomers used in these hydrogel:-

➤ *Polyacrylamide and Polyacrylate-Based Hydrogels*

In this hydrogels acylamide and acrylate monomers are used. Polyacrylamide and polyacrylate polymers are commonly employed as in soil conditioners because these have high swelling capacity (more than 2000 g water per gram dry polymer). These hydrogels are synthesized by using free radical polymerization, condensation polymerization, and UV irradiation processes. The acrylamide and acrylate monomers act as cross- linker. The cross-linking imparts structural stability, facilitate water absorption without dissolution.

➤ *Acrylic Acid-Based Hydrogels*

This type of hydrogels are synthesized by using vinyl groups monomers in which carboxyl functional group facilitate the polymerization in which acidic atmosphere maintained by the using of sulfuric or chlorosulfonic acid. Derivatives hydrogels are shows as cationic, anionic, neutral and amphoteric in nature that can produce interpolyelectrolyte complexes which facilitate the stabilization of soil. In sandy soil only 0.2-0.3% of these hydrogels can enhanced the 3-5 times water retention.

C. *Degradation and Limitations*

Degradation of synthetic polymeric hydrogels are very slow which influenced by type and climatic conditions of soil. Degradation is slow under moist conditions as compared to dry soils. Stability is relatively high at 20 °C, with decomposition rates of 0.04–0.2% per year, corresponding to lifetimes of 2–14 years. However, concerns persist about accumulation and possible release of toxic monomers.[31]

D. *Biopolymeric Hydrogels*

➤ *Cellulose-Based Hydrogels*

Hydrogels that derived from cellulose are frequently available having renewable and biodegradable nature. These can be obtained by caboxymethylcellulose (CMC) or agricultural waste materials like straw of rice and paper pulp. Cellulose is also obtained by the some genus of bacteria. The bacterial cellulose hydrogels have nanofibrillar structure that increased the water retention capacity than hydrogel obtained from plant derived cellulose hydrogel. These hydrogels have effectively control nutrient, improved seed germination degrade naturally in soil [31].

Table 1:- Some Natural Substances Based Hydrogels and their Role in Agricultural Field.

Category	Natural Polymer	Delivery Method	Role in Agriculture	Ref.
Polysaccharides	Chitosan	Nanoparticles, hydrogels, films	Sustain the release of pesticides, herbicides, and fertilizers; biodegradable and biocompatible carrier	[11, 12]
	Alginate	Microspheres, hydrogels, nanoparticles	Sustain the release of pesticides, herbicides, and plant growth regulators	13
	Cellulose	Nanofibers, microspheres, hydrogels	Sustain the release of pesticides and fertilizers	14
	Starch	Microspheres, nanoparticles, films	Sustain the release of pesticides and herbicides; biodegradable carrier	15
	Pullulan	Nanoparticles, microspheres	Sustain the release of pesticides and insecticides	16
	Pectin	Microspheres, nanoparticles	Sustain the release of pesticides and herbicides	17
	Dextran	Nanoparticles, microspheres	Sustain the release of pesticides and plant growth regulators	18
	Cyclodextrin	Inclusion complexes, nanoparticles	Sustain the release of pesticides and herbicides	19
	Hyaluronic Acid	Nanoparticles, hydrogels	Sustain the release of pesticides and plant growth regulators	20
	Carrageenan	Hydrogels, microspheres	Sustain the release of pesticides and fertilizers	21
	Konjac Glucomannan	Nanoparticles, microspheres	Sustain the release of pesticides and insecticides	22
	Agar	Nanoparticles, microspheres	Sustain the release of pesticides and fertilizers	23
Proteins	Gelatin	Microspheres, nanoparticles	Sustain the release of pesticides and plant growth regulators	24
Gums	Gum Arabic	Nanoparticles, microspheres	Sustain the release of pesticides and fertilizers	25
	Xanthan Gum	Hydrogels, microspheres	Sustain the release of pesticides and plant growth regulators	26
	Guar Gum	Hydrogels, microspheres	Sustain the release of pesticides and fertilizers	27
	Gum Ghatti	Microspheres, nanoparticles	Sustain the release of pesticides and	28

			herbicides	
	Gum Karaya	Hydrogels, microspheres	Sustain the release of pesticides and plant growth regulators	29
	Gum Tragacanth	Microspheres, hydrogels	Sustain the release of pesticides and herbicides	30

➤ *Collagen and Alginate Hydrogels*

Hydrogels that derived from collagen have high absorption capacity (up to 2208 g/g) and sustained release of nutrients. Sodium alginates a polysaccharide with linear structure have carboxyl and hydroxyl functional groups, which undergoes ionotropic gelation with calcium ions. This hydrogels exhibit swelling potential up to 55 g/g and in effect it enhanced crop development under arid stress [32].

➤ *Chitosan and Polyion Complex Hydrogels*

Chitosan is a cationic biopolymeric material that interacts with anionic charged polymers such like carboxymethylcellulose and produced polyion complexes. These gels improved soil structure, prevent soil erosion, and improved mechanical stability by electrostatic interactions between each other [33].

E. Semi Synthetic and Composite Hydrogels or Copolymer

The semi-synthetic polymeric hydrogels are a combination of natural and synthetic components polymer that improved functionality and sustainability. It can be synthesized by the using of natural and artificial components. These types of polymeric hydrogels are as Starch-acrylic acid copolymer, gaur gum-acrylamide blends and celluloses-polyvinyl alcohol composites that improved the absorption of water, natural degradability and capacity to release nutrients. In other hands it these hydrogels improved the water absorption and soil fertility [10].

F. Biodegradability of Hydrogels

➤ *Synthetic Polymeric Hydrogels*

This class of polymeric hydrogels shows slow degradation by partial microbial assimilation. Some bacteria and fungi degraded to the polyacrylamide and polyacrylates by enzymatic depolymerization [34].

➤ *Natural Polymeric Hydrogels*

Such hydrogels are readily degraded by enzymes available in soil such as amylases, cellulases, chitosanases, and alginate lyases.

➤ *Hybrid Systems*

Biodegradability of hybrid polymeric hydrogels depends on the proportion of natural polymers and synthetic monomers available in form of cross linker.

G. Hydrogels as Carriers for Fertilizers and Agrochemicals

➤ *Fertilizers*

Hydrogels encapsulate the nutrients viz urea, ammonium phosphate, and potassium salts in polymeric hydrogel and enhances the applied efficiency of nutrient and so that minimizes leaching. Composite hydrogels with oils, biochar, or nanoparticles have been designed for controlled release mechanism shown in Fig.2 [31].

➤ *Pesticides and Herbicides*

Hydrogel have micro porous matrices which helped into the regulation and release of pesticides including glyphosate, chlorpyrifos, and carbendazim. It also reduced the environmental contamination and improving application efficiency [31].

➤ *Biofertilizers and Microbial Carriers*

Hydrogels are bringing to hold valuable microorganisms (e.g., *Azospirillum*, *Bacillus* spp.), shielding them against ecological stresses and facilitate continued release in soil. The Chitosan–starch and alginate-based hydrogels have shown brilliant compatibility with soil microorganisms [35].

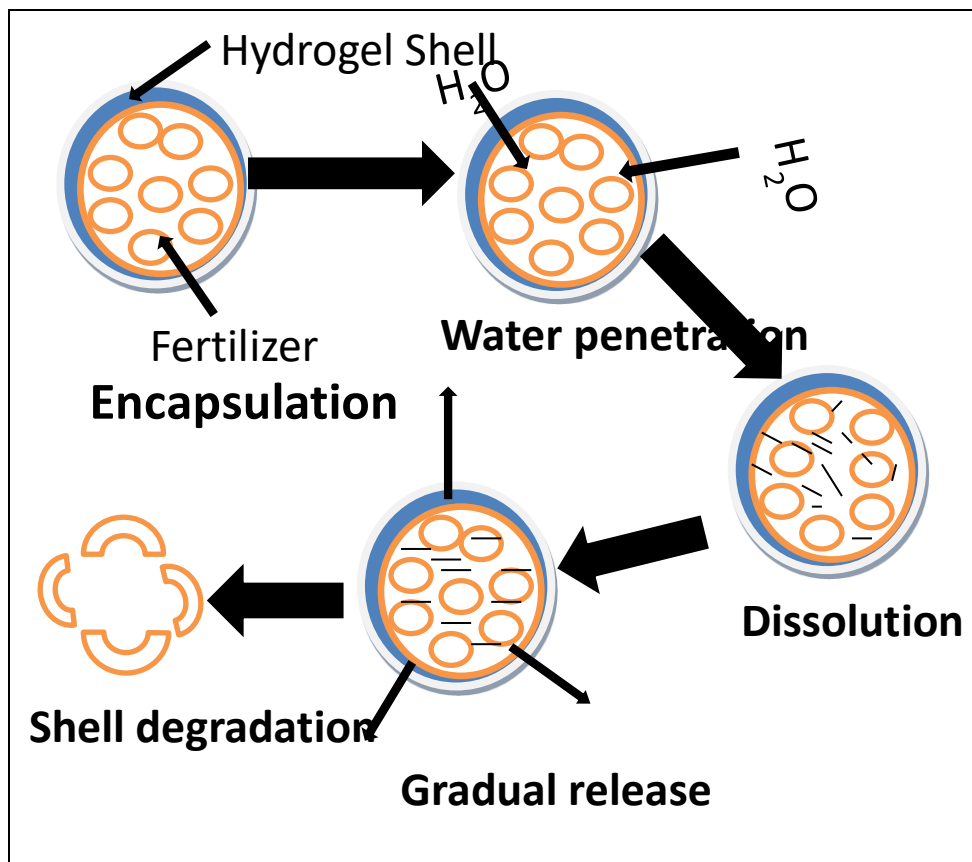


Fig: 2 Release of Compounds Encapsulated Mechanism in a Polymer Hydrogel

IV. EFFECT ON PLANT GROWTH AND PRODUCTIVITY

Experimental studies express the positive impact of polymeric hydrogels on diverse crops are shown in Table 2.

Table 2:- Impact of Polymeric Hydrogels on Diverse Crops

Crop Category	Name of Crop	Hydrogels positive Effect on crop	Ref
Cereal	Spring Wheat	Enhanced the use of water efficiency, accumulation of greater biomass and facilitate more grain yield	[36]
	Winter Wheat	Developed germination seed, tolerate better to the drought and improved yield.	[37-41]
	Barley	Better plant growth, higher number of grain and resist water stress.	[42]
	Corn (Maize)	Elevate chlorophyll matter, Boosted root growth and greater yields of grain.	[43-45]
Vegetable	Carrot	Boosted the seed germination, enhanced root weight and more productivity.	[46-47]
	Potato	Elevate size of tuber, highly retention capacity to soil moisture and gave overall yield.	[48]
	White Cabbage	Better vegetative growth and more water retention capacity	[46]
	Cucumber	Fruit yields high; elevate soil moisture condition and good nutrient uptake.	[49]
	Tomato	Improved quality of fruits, number of fruits and prolonged availability of water in soil.	[50-51]
	Radish	Much more germination, much root weight, improved drought resistance	[49] [52-54]
General Impact	Across Crops	Elevate soil water holding capacity, minimize irrigation frequency, enhanced nutrient uptake efficiency and higher yields	

Out of the above crops and vegetable shown in table 2, it also shows the positive impact on horticultural plants such as lettuce, guava and ornamental plants. Polymeric hydrogels

constantly elevate the seed germination, root growth, plant survival and yield especially in arid region that maintained

drought stress and up to 70% yield increases as compared to controls.

V. CHALLENGES AND FUTURE PROSPECTS

In spite of their demonstrated benefits, hydrogels are accepted on large-scale in agriculture is agricultural field with high production costs and the synthetic residues persistence in soil. Future research should focus on:

- Development of cost effective eco-friendly, biodegradable hydrogel formulations using agro-industrial wastes.
- Designing hybrid hydrogels that balance biodegradability, water retention and mechanical stability.
- Expanding valuable applications of hydrogel in microbial inoculation, precision nutrient delivery and climate resilient agriculture.

VI. CONCLUSION

The polymeric hydrogels correspond to a promising class of materials that more sustainable for agriculture. Through improving soil structure, water retaining, sustained nutrient release, and helpful towards microbial activity, polymeric hydrogels developed the crop performance, especially in arid region or under drought conditions. All the polymeric hydrogels likes synthetic, natural, and hybrid hydrogels each acquire unique advantages and limitations. Future advances of hydrogels in biodegradable and cost-effective hydrogel systems seized potential to transformation on agricultural practices toward greater resilience and sustainability.

REFERENCES

- [1]. S. Ameen, M. LeeMoon, S. Kang, J. Ho, C. Bong, S. Kim, "Three dimensional photo-cross-linkers for nondestructive photopatterning of electronic materials", *Acc. Mater. Res.*, vol 6 (3), pp 340–351, 2025.
- [2]. A Nath, A. Mishra, P. P. Pande, "A review natural polymeric coagulants in wastewater treatment", *Materials today proceeding*, vol 46 (14), pp 6113–6117, 2021.
- [3]. A. Mishra, A. Nath, P. P. Pande, R. Shankar, "Treatment of gray wastewater and heavy metal removal from aqueous medium using hydrogels based on novel crosslinkers", *J Appl Polym Sc*, vol. 138,(16), pp 5024, 2021.
- [4]. A. Nath, P. P. Pande, "Polyacrylamide Based Polymers: Smart Materials Used in Wastewater Treatment, *Adv. Sci. Eng. Med.*, vol 12 (1), pp. 105–107, 2020.
- [5]. H. Omar, E. Alsharaeh, "Improving Water Retention in Sandy Soils with High-Performance Superabsorbents Hydrogel Polymer," *ACS Omega*, vol 9 (22), 23531–23541, 2024.
- [6]. R. Elavenil, Rahale1C Sharmila, T Shanmugasundaram, G Ashokkumar, "Polymer-mediated delivery of agrochemicals," *Plant sci. today*, doi.org/10.14719/pst.7970, 2025.
- [7]. P. Kaur, R. Agrawal, F. M. Pfeer, R. Williams, H. B. Bohida, "Hydrogels in Agriculture: Prospects and Challenges," *J Polym Environ*, vol, 31(9):1-18, DOI:10.1007/s10924-023-02859-1, 2023.
- [8]. S. Arem, S. Patil, K. Archana, "USE Of Hydrogels In Agriculture, AgriGate- An International Multidisciplinary e-Magazine," vol 05 (03) pp 628, 2025.
- [9]. N. Muhammad, M. A. Kader, S. G. Al-Solaimani, M. Hassan, A. El-Wahed, R., A. Abohassan, M. E. Charle, "A review of impacts; of hydrogels on soil water conservation in dry land agriculture," *Farming System*, vol. 3(4), pp 100166, 2025.
- [10]. F. Ullah, M. Bisyrul, H.afi Othman, F. Javed, Z. Ahmad, H. Md. Akil, "A Review, Classification, processing and application of hydrogels: A review," *Mat Sci Eng C*, vol 57, -433, 2015.
- [11]. V.R. Sinha, A.K. Singla, S. Wadhawan, R. Kaushik, R. Kumria, K. Bansal, "Chitosan microspheres as a potential carrier for drugs," *Int. J. Pharm*, 274 (1–2), 1–35, 2004.
- [12]. K.C. Gupta, F.H. Jabrail, "Effects of degree of deacetylation and cross-linking on physical characteristics, swelling and release behavior of chitosan microspheres," *Carbohydr. Polym.*, vol 66(1), pp 43–54, 2006.
- [13]. P.L. Kashyap, X. Xiang, P. Heiden, "Chitosan nanoparticle-based delivery systems for sustainable agriculture," *Int. J. Biol. Macromol.*, vol 77, pp 36–51, 2015.
- [14]. Khoe S, Yaghoobian M. An investigation into the role of surfactants in controlling particle size of polymeric nanocapsules containing penicillin-G in double emulsion. *European Journal of Medicinal Chemistry*. vol 44(6), pp 2392–9, 2009.
- [15]. N.V.N. Jyothi, P.M. Prasanna, S.N. Sakarkar, K.S. Prabha, P.S. Ramaiah, G.Y. Srawan, "Microencapsulation techniques, factors influencing encapsulation efficiency," *J Microencapsul*, vol 27(3), pp 87–97, 2010.
- [16]. L. Ferreira, M.M. Vidal, M.H. Gil, "Evaluation of poly(2-hydroxyethyl methacrylate) gels as drug delivery systems at different pH values," *Int. J. Pharm.*, vol 326(1–2) pp 1–13, 2006.
- [17]. P. Sriamornsak, "Chemistry of pectin and its pharmaceutical uses: A review," *Silpakorn University International Journal*. Vol 3(1–2), pp 206–28, 2003.
- [18]. Q. Xiong, W. Liang, W. Shang, Z. Xie, J. Cheng, B. Yu, "Bidirectional uptake, transfer and transport of dextran dextran-based nanoparticles in plants for multidimensional enhancement of pesticide utilization" *Small*, vol 20(8), pp 2305693, 2024.

- [19]. Z. Liu, W. Xu, E.G. Kovaleva, J. Cheng, H.Li, "Recent progress in encapsulation and controlled release of pesticides based on cyclodextrin derivative carriers," *Adv. Agrochem.*, vol 1(2), pp 89–99, 2022.
- [20]. G. Tiwari, R. Tiwari, B. Sriwastawa, L. Bhati, S. Pandey, P. Pandey, "Drug delivery systems: An updated review," *Int. J. Pharm. Investig.*, vol 2(1), pp 2–11, 2012.
- [21]. M.K. Azeem, A. Islam, M. Rizwan, A. Rasool, N. Gul, R.U. Khan, "Sustainable and environment friendlier carrageenan-based pH-responsive hydrogels: Swelling behavior and controlled release of fertilizers," *Colloid Polym Sci.*, vol 301(3), pp 209–19, 2023.
- [22]. X. Li, S. Wang, Z. Sun, M. Gao, Q. Li, M. Qin, "Study on Enteromorpha polysaccharide/Konjac glucomannan mulch films with biochar as a fertilizer carrier," *ACS Appl. Polym. Mater.*, vol 6(12), pp 6946–56, 2024.
- [23]. B. Singh, D.K. Sharma, S. Negi, A. Dhiman, "Synthesis and characterization of agar-starch based hydrogels for slow herbicide delivery applications," *Int. J. Plast. Technol. or Int. J. Plast. Tech.*, vol 19, pp 263–74, 2015.
- [24]. S. Park, M. Safdar, W. Kim, J. Seol, D. Kim, K.H. Lee, "Gelatin nanoparticles can improve pesticide delivery performance to plants," *Small*, 2024;20(42):2402899.
- [25]. V.R. Sinha, R. Kumria, "Microbially triggered drug delivery to the colon," *FEMS Microbiol. Lett.*, vol 217(1), pp 1–7, 2003.
- [26]. B.S. Kaith, R. Jindal, M. Kumari, M. Kaur, "Biodegradable-stimuli sensitive xanthan gum based hydrogel: evaluation of antibacterial activity and controlled agro-chemical release," *React. Funct. Polym.*, vol 120, pp 1–3, 2017.
- [27]. P. Sriamornsak, "Chemistry of pectin and its pharmaceutical uses: A review," *Silpakorn University Int. J.*, vol 3(1–2), pp 206–28, 2003.
- [28]. B. Singh, N. Chauhan, S. Kumar, "Synthesis, characterization and swelling studies of pH-responsive psyllium and polyacrylamide based hydrogels for the use in drug delivery," *Carboh. Polym.*, vol 73(2), pp 201–10, 2008.
- [29]. S. Mao, W. Sun, T. Kissel, "Chitosan-based formulations for delivery of DNA and siRNA," *Adv Drug Deliv Rev.*, vol 62(1), pp 12–27, 2010.
- [30]. V. Kumar, H. Mittal, S.M. Alhassan, "Biodegradable hydrogels of tragacanth gum polysaccharide to improve water retention capacity of soil and environment-friendly controlled release of agrochemicals," *Int J of Bio Macromol.*, vol 132, pp 1252–61, 2019.
- [31]. G. Yu, V.A. Maksimova, A. Yu. Shchetko, Maksimov, "Polymer Hydrogels In Agriculture (review)," *Agri Bio*, vol 58(1), pp. 23-42, 2023.
- [32]. M. Baniasadi, M. Minary-Jolandan, "Alginate-Collagen Fibril Composite Hydrogel," *Mater*, vol 8 pp 799-814, 2015.
- [33]. P. Domalik-Pyzik, J. Chłopek, K. Pielichowska, "Chitosan-Based Hydrogels: Preparation, Properties, and Applications, Cellulose-Based Superabsorbent," *Hydrog*, pp 1665–1693, 2019.
- [34]. W. A. Najwa, W. Anuar, R. A. Ramli, M.M. El-Sayed, S.G. Warkar, "Recent study on biodegradable hydrogels for agriculture application: A review," *J Env Chem Eng*, vol 13(2), pp 115679, 2025.
- [35]. K. Ali, Z. Asad, H. D. Gamareldawla, Agbna, A. Saud, A. Khan, S. J. Zaidi, "Progress and Innovations in Hydrogels for Sustainable Agriculture A review," *Agronom*, 14(12), pp 2815, 2024.
- [36]. T.N. Danilova, L.K. Tabyimbaeva, "Polymer gels to manage water availability for wheat (*Triticum aestivum* L.) under various environment conditions," *Sel'skokhozyaistvennaya biologiya, [Agri Bio]*, vol 54(1), pp 76-83, 2019.
- [37]. A.P. Tibir, V.I. Filin, *Izvestiya Nizhnevolzhskogo agrouniversitetskogo kompleksa*, vol 3(27), pp 1-5, 2012 (in Russ.).
- [38]. E.N. Kuzin, Aref'ev A.N. *Zemledelie*, (in Russ.), vol 2 pp 12-14, 2013.
- [39]. E.I. Godunova, V.N. Gundyryn, S.N. Shkabarda, *Dostizheniya nauki i tekhniki APK*, vol 1, pp 24-27, 2014 (in Russ.).
- [40]. E.I. Godunova, V.N. Gundyryn, S.N. Shkabarda, *Dostizheniya nauki i tekhniki APK*, (in Russ.), 31(5), pp, 2017.
- [41]. V.N. Gundyryn, E.I. Godunova, S.N. Shkabarda, *Dostizheniya nauki i tekhniki APK*, (in Russ.) vol 30(8), pp 37-39, 2016.
- [42]. J.A. Akhter, J. Akhter, K.A. Mahmood, K.A. Malik, A. Mardan, M. Ahmad, M.M. Iqbal, "Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea, Plant," *Soil Environ*, vol 50(10) pp 463-469, 2004.
- [43]. N. Mazloom, R. Khorassani, G.H. Zohury, H. Emami, J. Whalen, "Lignin-based hydrogel alleviates drought stress in maize," *Environl Exp. Bot.*, vol 175, pp 104055, 2020.
- [44]. G. Dong, Z. Mu, D. Liu, L. Shang, W. Zhang, Y. Gao, M. Zhao, X. Zhang, S. Chen, M. Wei, "Starch phosphate carbamate hydrogel based slow-release urea formulation with good water retention," *Int J Biolo Macromol*, vol 190, pp 189-197, 2021.
- [45]. A.A. Albalasmeh, O. Mohawesh, M.A. Gharaibeh, A.G. Alghamdi, M.A. Alajlouni, A.M. Alqudah, "Effect of hydrogel on corn growth, water use efficiency, and soil properties in a semi-arid region," *J Saudi Soc Agri Sci*, vol 21(8), pp 518-524, 2022.
- [46]. Danilova T.N. *Izvestiya Sankt-Peterburgskogo gosudarstvennogo agrarnogo universiteta*, (in Russ.), vol 52: 3839 pp 47-53, 2018.
- [47]. Yu.A. Bykovskiy, M.I. Azopkov, S.V. Fefelova, D.S. Akimov, R.A. Bagrov, *Kartofel i ovoshchi*, (in Russ.), vol 1, pp 18-2, 2018.

- [48]. V.I.Starovoytov, O.A. Starovoytova, A.A. Manokhina, Vestnik Federal'nogo gosudarstvennogo obrazovatel'nogo uchrezhdeniya vysshego professional'nogo obrazovaniya, Moskovskiy gosudarstvennyy agroinzhenernyy universitet imeni V.P. Goryachkina»(in Russ.), vol 1(65), pp 15-19, 2015.
- [49]. F.F. Montesano, A. Parente, P.Santamaria, A.Sannino, F.Serio, "Biodegradable superabsorbent hydrogel increases water retention properties of growing media and plant growth," *Agri Agricul Sci Procedia*, vol 4, pp 451-458, 2015.
- [50]. H.H. Hernández, A.Benavides-Mendoza, H.Ortega-Ortiz, A.D.Hernández-Fuentes, A.D. Juárez-Maldonado, "Cu nanoparticles in chitosan-PVA hydrogels as promoters of growth, productivity and fruit quality in tomato," *Emir J Food Agri*, vol 29(8), pp 573-580, 2017.
- [51]. J.Tanasić, T.Erceg, L.Tanasić, S.Baloš, O.Klisurić, I. Ristić, "The influence of reaction conditions on structural properties and swelling kinetics of polyurethane hydrogels intended for agricultural purposes," *React Funct Polym*, vol 169, pp 105085, 2021.
- [52]. A.A.Okolelova, N.A.Rachimova, G.S.Egorova, N.G.Kasterina, V.N. Zaikina, "Influence of hydrogels on productivity of light-brown soils," *Int J Env Prob*, vol 2(2), pp 117-135,2015.
- [53]. T.G. Voskoboinikova, A.A.Okolelova, R.O. Manov, Nauchnye vedomosti. Seriya Estestvennye nauki, (in Russ.), vol 9(31), pp 37-42, 2015.
- [54]. S.Durpekova, E.D.Bergerova, D.Hanusova, M.Dusankova, V.Sedlarik, "Ecofriendly whey/polysaccharide-based hydrogel with poly(lactic acid) for improvement of agricultural soil quality and plant growth," *Int J Bio Macromol*, vol 212, pp 85-96, 2022.