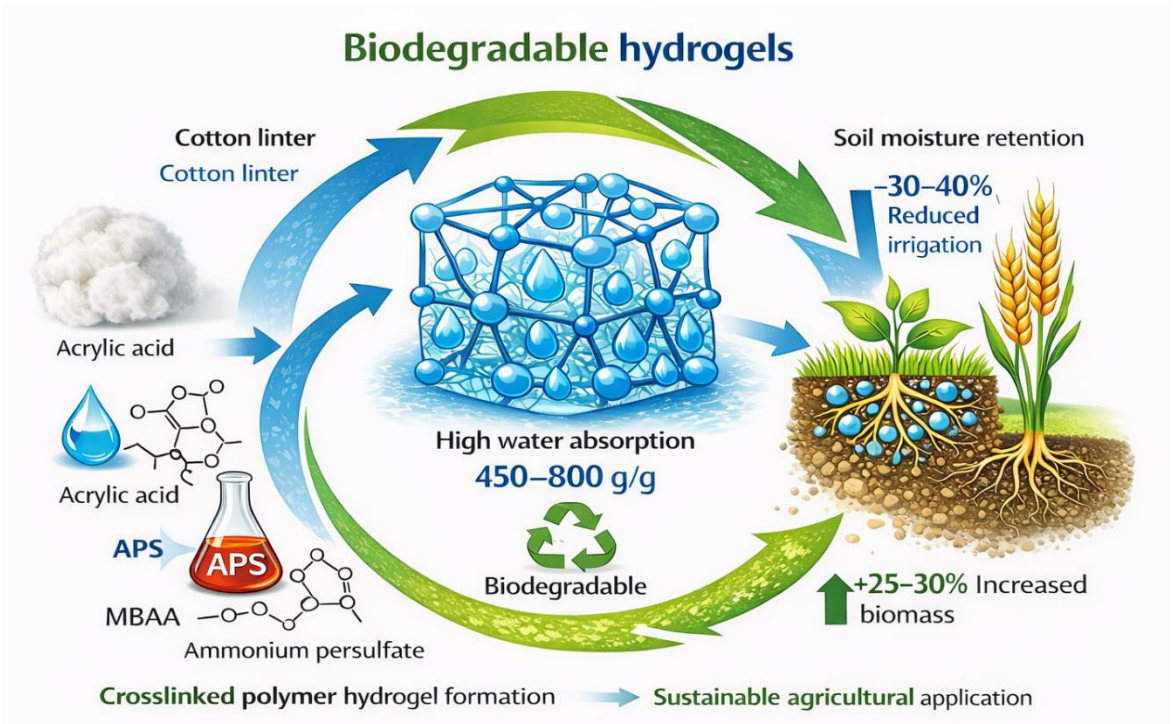
INNOVATIONS IN TECHNOLOGY AND SCIENCE EDUCATION
ISSN 2181-371X
https://sr-journals.org/index.php/ITSE

SYNTHESIS OF BIODEGRADABLE COTTON LINTER HYDROGELS FOR IMPROVING SOIL MOISTURE RETENTION IN ARID RAINFED AGRICULTURE OF THE ARAL SEA BASIN

Tursunali Nasrullaevich Eshburiev
Senior Lecturer, Tashkent Chemical-Technological Institute,
Republic of Uzbekistan, Tashkent
E-mail: tursunalihim@gmail.com,
Shavkat Shirinov *PhD, Assoc. Prof.,*
Tashkent Research Institute of Chemical Technology (TNIICHT),,
Republic of Uzbekistan, Tashkent
E-mail: shirinov-shavkat@mail.com
Abdugani Mutalovich Azimov
PhD, M. Auezov South Kazakhstan University. Head of the Research Laboratory "Innovative Water Purification Systems"
E-mail: azimov-78@mail.ru.



Graphical Abstract. *Schematic illustration of biodegradable hydrogels synthesized from cotton linter and acrylic acid, showing high water absorption capacity, biodegradability, improved soil moisture retention, reduced irrigation demand, and enhanced plant biomass.*

Annotatsiya. Paxta linti asosidagi bioparchalanuvchi gidrogellar qisman neytrallangan akril kislotaning erkin radikal usulida tarmoqlanishi orqali sintez qilindi. Uch o‘lchamli polimer tarmog‘ini hosil qilish uchun ammoniy persulfat iniciator sifatida, N,N′-metilenbisakrilamid esa tarmoqlovchi modda sifatida qo‘llanildi. Olingan gidrogellar distillangan suvda (450–800 g/g), tuzli eritmada (120–250 g/g) hamda turli pH muhitlarida yuqori suv yutish qobiliyatini namoyon etdi. Tuproqda ko‘milish

sharoitida olib borilgan tajribalar natijasida 180 kun davomida gidrogel massasining 70–85 % gacha kamayishi kuzatilib, ularning bosqichma-bosqich bioparchalanishini ko‘rsatdi. Vegetatsion tajribalar natijalari tuproq namligini saqlash darajasi oshganini hamda nazorat variantiga nisbatan o‘simlik biomassasi 28 % gacha ortganini ko‘rsatdi. Olingan natijalar paxta linti asosida olingan tarmoqlangan gidrogellar qishloq xo‘jaligida suv resurslarini samarali boshqarish uchun istiqbolli va ekologik xavfsiz material ekanligini ko‘rsatadi. Ushbu gidrogel tizimi ayniqsa Orolbo‘yi hududining lalmi qishloq xo‘jaligi yerlarida suvdan foydalanish samaradorligini oshirish uchun muhim ahamiyatga ega, chunki bu hududlarda suv tanqisligi va tuproq degradatsiyasi hosildorlikni keskin cheklaydi. Olingan materiallar sug‘orish suviga bo‘lgan ehtiyojni kamaytirish va qurg‘oqchilik sharoitida ekinlarning chidamliligini oshirish imkonini beradi. Ishlab chiqilgan bioparchalanuvchi gidrogel Markaziy Osiyoning qurg‘oqchil agroekotizimlarida tuproq namligini saqlash, suvdan foydalanish samaradorligini oshirish va qurg‘oqchilik stressini kamaytirish uchun barqaror tuproq konditsioneri sifatida qaralishi mumkin.

Kalit so‘zlar: Bioparchalanuvchi gidrogellar, paxta linti, lalmi qishloq xo‘jaligi, Orolbo‘yi hududi, tuproq namligini saqlash, suv tanqisligi

Аннотация. Биоразлагаемые гидрогели на основе хлопкового линта были синтезированы методом радикальной сшивки частично нейтрализованной акриловой кислоты. В качестве инициатора использовался персульфат аммония, а N,N′-метиленбисакриламид применялся как сшивающий агент для формирования трёхмерной полимерной сети. Полученные гидрогели показали высокую водопоглощающую способность в дистиллированной воде (450–800 г/г), в солевом растворе (120–250 г/г), а также в средах с различным pH. Почвенные испытания методом захоронения показали постепенную биодеградацию материала с потерей массы на уровне 70–85 % после 180 суток. Вегетационные эксперименты продемонстрировали улучшение удержания влаги в почве и увеличение биомассы растений до 28 % по сравнению с контрольным вариантом. Полученные результаты свидетельствуют о том, что сшитые гидрогели на основе хлопкового линта являются перспективными экологически безопасными материалами для управления водными ресурсами в сельском хозяйстве. Разработанная гидрогелевая система особенно перспективна для повышения эффективности использования воды в богарных почвах Приаралья, где дефицит водных ресурсов и деградация почв существенно ограничивают урожайность сельскохозяйственных культур. Полученные материалы способны снизить потребность в орошении и повысить устойчивость растений к засухе в условиях аридного климата. Разработанный биоразлагаемый гидрогель может рассматриваться как устойчивый почвенный кондиционер, способный повышать эффективность использования воды и снижать засуховый стресс в аридных агроэкосистемах Центральной Азии.

Ключевые слова: Биоразлагаемые гидрогели, хлопковый линт, богарное земледелие, регион Приаралья, удержание влаги в почве, дефицит воды

Abstract. Biodegradable hydrogels based on cotton linter were synthesized via free-radical crosslinking of partially neutralized acrylic acid. Ammonium persulfate was used as an initiator and N, N′-methylenebisacrylamide as a crosslinker to form a three-dimensional polymer network. The hydrogels exhibited high water absorption capacities in distilled water (450–800 g/g), saline solution (120–250 g/g), and pH-dependent media. Soil burial tests showed gradual biodegradation with 70–85% mass loss after 180 days. Pot experiments demonstrated improved soil moisture retention and increased plant biomass by up to 28% compared to the control. These results indicate that cotton linter-based crosslinked hydrogels are promising, environmentally friendly materials for agricultural water management. The developed hydrogel system is particularly promising for improving water-use efficiency in rainfed agricultural soils of the Aral Sea region, where water scarcity and soil degradation significantly limit crop productivity. The obtained materials can reduce irrigation demand and enhance drought resistance of crops under arid climatic conditions. The developed biodegradable hydrogel can

be considered a sustainable soil conditioner **that improves** water-use efficiency and **mitigates** drought stress in arid agroecosystems of Central Asia.

Keywords: Biodegradable hydrogels, cotton linter, rainfed agriculture, Aral Sea region, Soil moisture retention, water scarcity

Introduction

In recent decades, global climate change and increasing water scarcity have had a serious impact on the sustainability of agricultural production. According to reported studies, water deficit in arid and semi-arid regions can lead to a reduction in crop productivity by 20–50% [1]. Therefore, the development of materials capable of retaining water in soil and ensuring its efficient uptake by plants has become an important scientific and practical challenge.

In this context, superabsorbent polymers (SAPs), particularly biodegradable hydrogels, have gained considerable attention due to their ability to absorb large amounts of water and gradually release it into the plant root zone [2,3]. Although conventional polyacrylate-based hydrogels exhibit high water absorption efficiency, their long-term persistence in soil and poor biodegradability pose potential environmental risks [4]. Consequently, recent research has increasingly focused on biodegradable hydrogels derived from natural polymers.

The Aral Sea region of Central Asia represents one of the most severe ecological disaster zones in the world. Intensive water withdrawal for irrigation and climate change have led to desertification, soil salinization, and increasing water scarcity. As a result, large areas of agricultural land have become rainfed or semi-arid systems where crop productivity strongly depends on soil moisture conservation. Therefore, the development of environmentally friendly materials capable of retaining water in soil is of particular importance for sustainable agriculture in this region.

Therefore, the objective of this study was to synthesize biodegradable hydrogels based on cotton linter and acrylic acid and to evaluate their potential for improving soil moisture retention and plant growth under arid rainfed agricultural conditions of the Aral Sea basin.

Literature Review

Hydrogels are three-dimensional, crosslinked polymer networks capable of swelling in aqueous environments. Peppas et al. classified hydrogels based on their swelling behavior, mechanical properties, and biocompatibility, highlighting their broad application potential [5]. In contrast to conventional synthetic hydrogels, biodegradable hydrogels are able to decompose into low-molecular-weight compounds under the influence of soil microorganisms, enzymes, and moisture [6].

Numerous studies have demonstrated that hydrogels synthesized from natural polymers significantly improve soil water retention and create a favorable microenvironment for plant growth [7]. Among natural polymers, cellulose and its derivatives, such as sodium carboxymethyl cellulose (Na-CMC), hydroxyethyl cellulose (HEC), and carboxymethyl cellulose (CMC), are the most extensively investigated raw materials for the preparation of biodegradable hydrogels [8]. The abundance of hydroxyl groups in cellulose makes it a suitable substrate for chemical modification and polymer network formation.

Cotton linter is a highly purified form of cellulose and is distinguished by its low cost and renewability. Zhou et al. reported that hydrogels prepared from cotton fibers exhibit high water absorption capacity and good mechanical stability [9]. Furthermore, hydrogels obtained by incorporating acrylic monomers into cotton linter have been identified as promising materials for agricultural applications [10].

Acrylic acid and its salts are widely used in the synthesis of superabsorbent hydrogels due to their strong hydrophilicity. Through free-radical polymerization mechanisms, acrylic acid can be integrated into polymer networks, forming highly water-absorbent three-dimensional crosslinked structures [11]. Literature data indicate that increasing the content of crosslinking agents enhances the mechanical strength of hydrogels; however, beyond an optimal level, excessive crosslinking leads to a

decrease in swelling capacity [12]. This balance is particularly important when designing hydrogels for agricultural use.

Numerous laboratory and field studies have demonstrated that the application of biodegradable hydrogels in soil can reduce irrigation water consumption by 30–50% [13]. Islam et al. reported that the use of hydrogels increased maize and wheat yields by 20–30% under water-limited conditions [14]. In cotton cultivation, hydrogels have been shown to retain moisture in the root zone for extended periods, thereby reducing drought stress and improving plant development [15]. In addition, biodegradable hydrogels offer a significant advantage by not causing adverse effects on soil ecology [16].

Overall, the reviewed literature indicates that biodegradable hydrogels are promising materials for improving agricultural efficiency under water-scarce conditions. However, the development of hydrogels based on locally available and inexpensive raw materials such as cotton linter, as well as their evaluation under real agro-climatic conditions, remains insufficiently explored. The present study aims to address this research gap.

Recent studies indicate that the application of superabsorbent hydrogels in rainfed agriculture significantly improves soil moisture storage and reduces drought stress in crops. Such materials can act as temporary water reservoirs in the root zone, gradually releasing absorbed water during dry periods. However, the development of biodegradable hydrogels based on locally available raw materials such as cotton linter and their application under the agro-climatic conditions of the Aral Sea basin remains insufficiently investigated.

2. Materials and Methods

In this study, biodegradable hydrogels were synthesized using a combination of natural and synthetic components. Highly purified cotton linter (with an α-cellulose content of not less than 95%) was selected as the primary natural raw material. Acrylic acid was used as the synthetic monomer. Sodium hydroxide was employed for the partial neutralization of acrylic acid, ammonium persulfate (APS) served as a free-radical initiator, and N,N′-methylenebisacrylamide (MBAA) was used as a crosslinking agent to form a three-dimensional polymer network. Distilled water was used throughout all synthesis and characterization procedures.

The selection of these materials and reagents was based on their widespread use and proven efficiency in the synthesis of biodegradable hydrogels, as reported in the scientific literature.

The pot experiments were carried out under laboratory conditions at a temperature of 25 ± 2 °C. Soil moisture content was measured gravimetrically at regular intervals to evaluate the water retention capacity of hydrogel-treated soil.

Prior to hydrogel synthesis, cotton linter was pretreated to enhance its reactivity. The pretreatment involved mechanical grinding followed by alkaline treatment. Alkaline activation promotes the exposure and activation of hydroxyl groups within the cellulose chains, thereby facilitating subsequent free-radical crosslinking reactions. After alkaline treatment, the cotton linter was thoroughly washed with distilled water until neutral pH was achieved and then dried.

Biodegradable hydrogels were synthesized via free-radical crosslinking polymerization by incorporating acrylic acid into the cotton linter matrix. Acrylic acid was partially neutralized prior to polymerization in order to enhance the hydrophilicity of the resulting hydrogel. Ammonium persulfate was used as the initiator, generating free radicals at elevated temperatures and initiating the polymerization process. The formation of a three-dimensional crosslinked polymer network was achieved through the addition of MBAA as the crosslinking agent.

To evaluate the agricultural performance of the synthesized hydrogels, soil typical for arid and rainfed agricultural areas was used in laboratory model experiments. The soil was characterized by low moisture retention capacity and moderate salinity, which is typical for soils of the Aral Sea region.

Free-radical crosslinking mechanism for the formation of a biodegradable hydrogel based on cotton linter (cellulose) and acrylic acid

1. Activation of cellulose chains

Cellulose chains derived from cotton linter are activated in the presence of ammonium persulfate ($S_2O_8^{2-}$). Upon thermal decomposition, persulfate ions generate sulfate radicals, which abstract hydrogen atoms from the hydroxyl (–OH) groups of cellulose. As a result, cellulose macroradicals (Cell–O•) are formed.

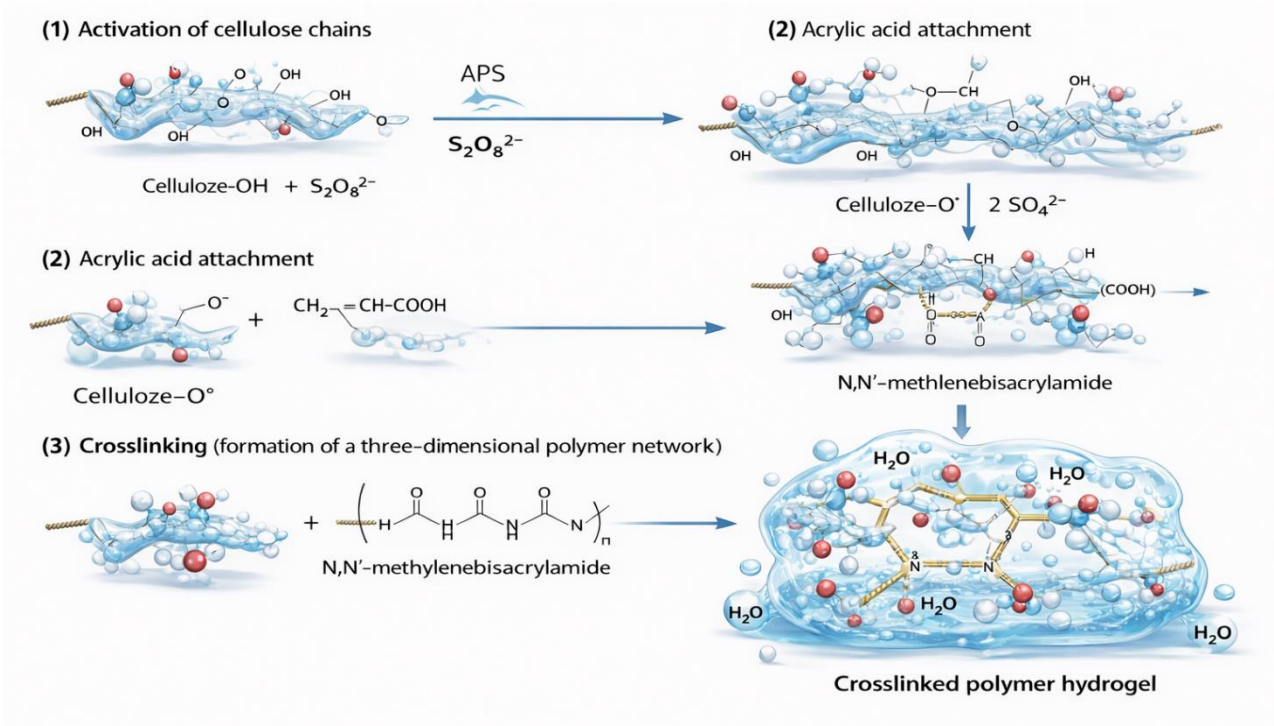
2. Chain propagation via acrylic acid polymerization

The generated cellulose radicals attack the carbon–carbon double bonds of acrylic acid monomers. This leads to the growth of poly(acrylic acid) chains chemically linked to the cellulose backbone, resulting in the formation of polymer chains anchored onto the cellulose skeleton. The polymerization reaction was carried out at 60–70 °C under continuous stirring for 2 hours until a stable hydrogel network was formed.

3. Crosslinking process

N,N′-methylenebisacrylamide acts as a crosslinking agent by connecting adjacent polymer chains through covalent bonds. This process results in the formation of a three-dimensional crosslinked polymer network.

The resulting structure is an elastic, highly water-absorbent, and biodegradable crosslinked polymer hydrogel capable of retaining large amounts of water and gradually releasing it under soil conditions.



Scheme 1. *Schematic illustration of the free-radical crosslinking mechanism for the formation of a biodegradable crosslinked polymer hydrogel based on cotton linter (cellulose) and acrylic acid: (1) activation of cellulose chains by ammonium persulfate, (2) propagation through acrylic acid attachment, and (3) crosslinking via N,N′-methylenebisacrylamide to form a three-dimensional polymer network.*

(1) **Activation of cellulose chains:** Cellulose chains derived from cotton linter are activated in the presence of ammonium persulfate ($S_2O_8^{2-}$). Thermal decomposition of persulfate ions generates sulfate radicals, which abstract hydrogen atoms from hydroxyl (–OH) groups of cellulose, resulting in the formation of cellulose macroradicals (Cell–O•).

(2) **Polymer chain formation via acrylic acid grafting:** The generated cellulose radicals attack the carbon–carbon double bonds of acrylic acid monomers. As a result, poly(acrylic acid) chains are grafted onto the cellulose backbone, forming cellulose-based polymer chains.

(3) **Crosslinking process:** N,N′-methylenebisacrylamide acts as a crosslinking agent, connecting adjacent polymer chains through covalent bonds and leading to the formation of a three-dimensional crosslinked polymer network.

3. Results and Discussion

3.1 Swelling kinetics of hydrogels

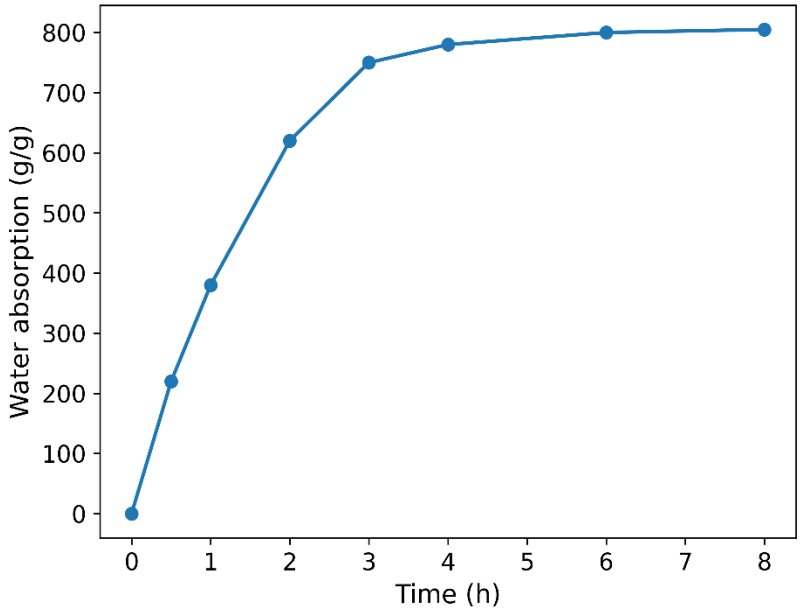


Figure 1. Swelling kinetics of biodegradable cotton linter–based hydrogels in distilled water

Figure 1 illustrates the swelling kinetics of the synthesized hydrogels. Rapid water uptake was observed during the first 2–3 hours, followed by a gradual approach to equilibrium swelling. This behavior is attributed to the presence of hydrophilic carboxyl groups within the crosslinked polymer network. Similar swelling behavior has been reported for cellulose-based hydrogels synthesized from natural polymers, confirming that the presence of hydrophilic functional groups significantly enhances water absorption capacity.

3.2 Soil moisture retention

The effect of hydrogel application on soil moisture retention is presented in **Figure 2**. Compared to the control soil, hydrogel-treated soil retained moisture for a significantly longer period, with 30–40% higher moisture content over time. This demonstrates the ability of hydrogels to act as water reservoirs in the root zone.

This effect is particularly important for rainfed agricultural systems of the Aral Sea region, where precipitation is limited and soil moisture rapidly evaporates under high temperatures. The hydrogel acts as a water reservoir, reducing moisture loss and maintaining favorable conditions for plant growth.

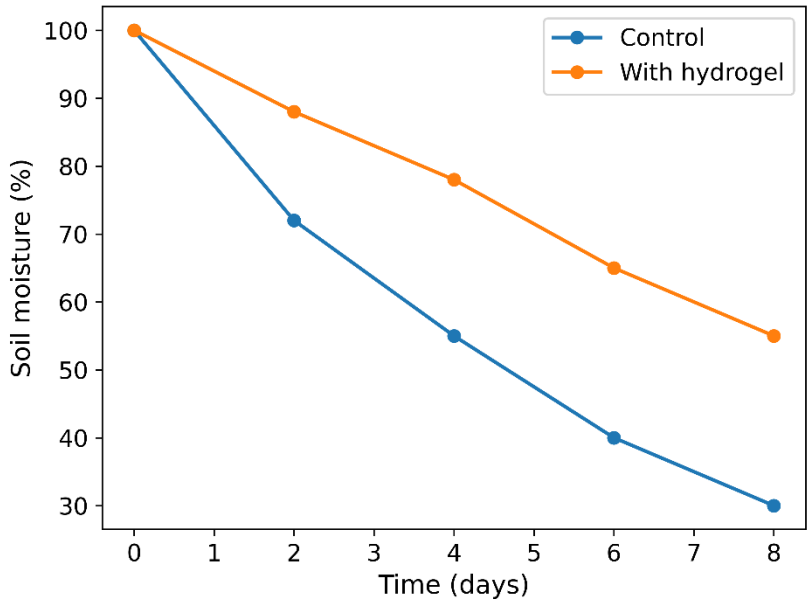


Figure 2. Comparison of soil moisture retention in control and hydrogel-treated soil.

3.3 Effect of hydrogel dosage on plant biomass

The influence of hydrogel concentration on plant biomass formation is shown in **Figure 3**. Increasing the hydrogel dosage from 0.5 to 2.0 g/kg soil resulted in a gradual increase in biomass. The optimal dosage (1.0–2.0 g/kg) enhanced biomass production by up to 28%.

These results confirm that the hydrogel improves water availability in the root zone and reduces drought stress, which is particularly important for crop production in rainfed farming systems of arid regions.

3.4 Biodegradation behavior

Soil burial tests confirmed the biodegradability of the synthesized hydrogels. As shown in **Figure 4**, hydrogel mass loss increased from 10–15% after 30 days to 70–85% after 180 days, indicating gradual degradation under natural soil conditions.

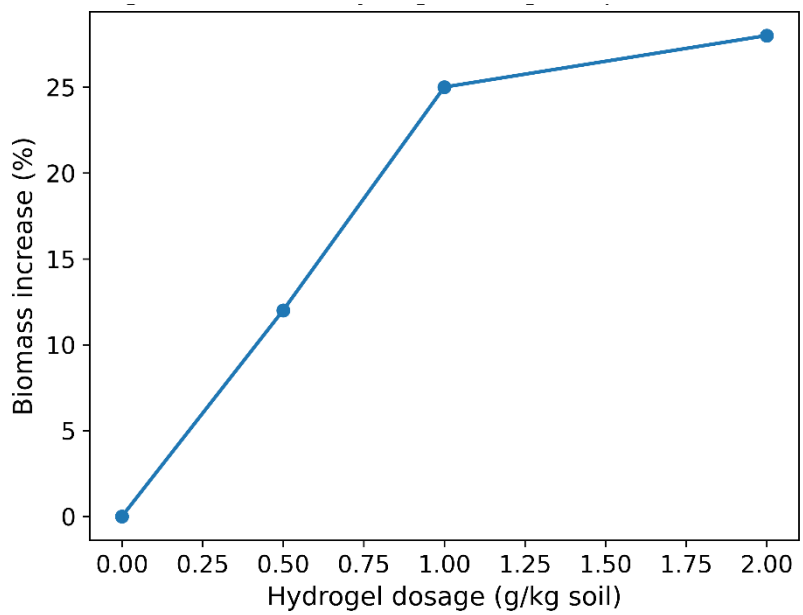


Figure 3. Influence of hydrogel dosage on plant biomass under rainfed soil conditions.

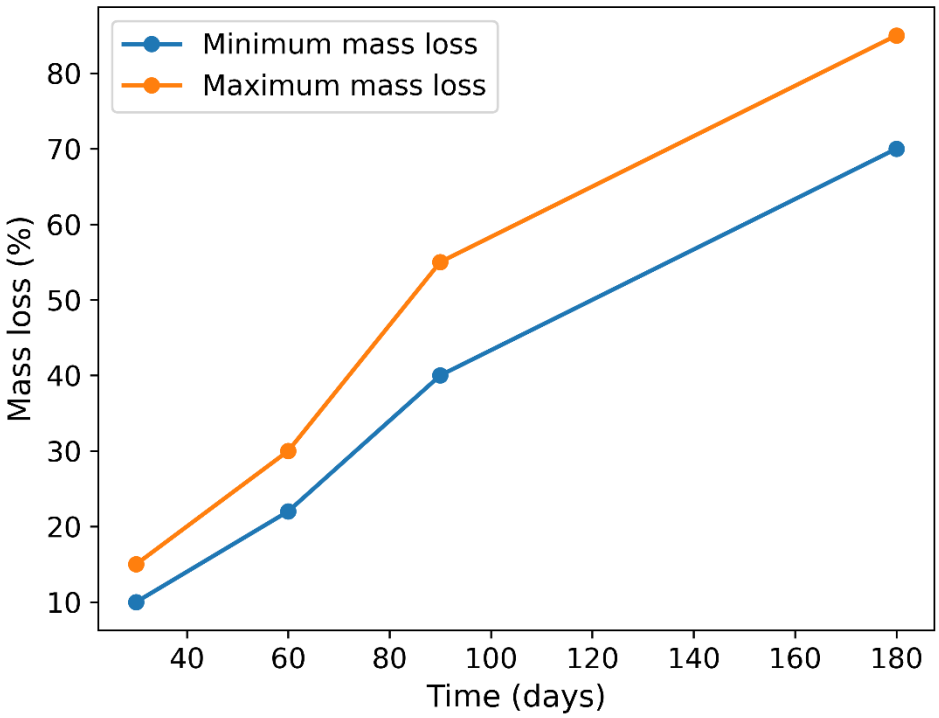


Figure 4. Mass loss of hydrogels during soil burial tests over time.

3.5 Effect of crosslinker content on gel fraction

The relationship between MBAA content and gel fraction is presented in **Figure 5**. Increasing the crosslinker concentration from 0.05% to 0.20% led to an increase in gel fraction from 72% to 90%, confirming enhanced network stability with higher crosslinking density.

3.6 Water absorption in different media

Water absorption capacities in various media are summarized in **Figure 6**. The hydrogels showed the highest swelling in distilled water, reduced swelling in saline solution, and pH-dependent behavior in acidic and alkaline environments.

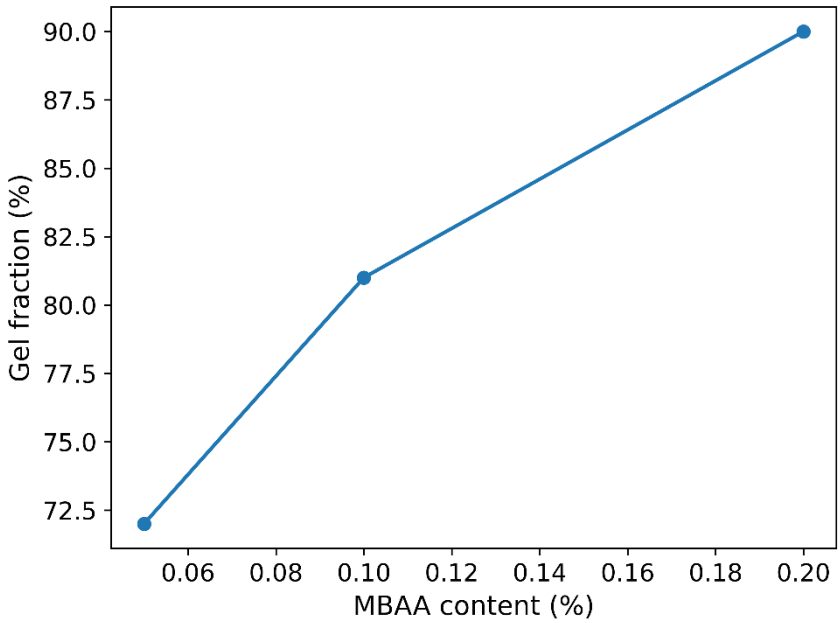


Figure 5. Effect of crosslinker (MBAA) content on gel fraction.

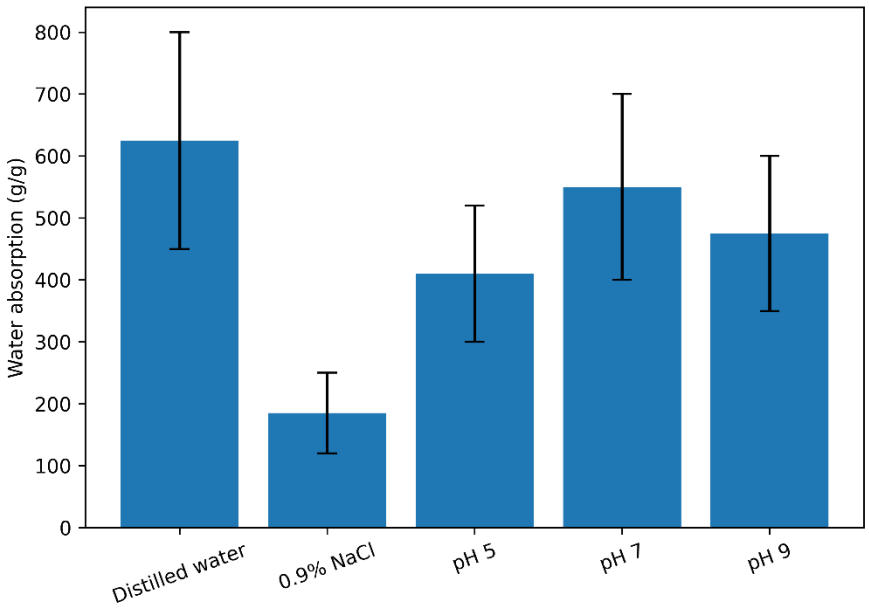


Figure 6. Water absorption capacity of hydrogels in different aqueous media.

Conclusions

In this study, biodegradable crosslinked polymer hydrogels based on cotton linter and acrylic acid were successfully synthesized via free-radical crosslinking polymerization. The use of cotton linter as a renewable and highly purified cellulose source enabled the formation of an environmentally friendly hydrogel system with high water absorption capacity and controlled biodegradability.

The synthesized hydrogels exhibited rapid swelling kinetics and high equilibrium water absorption, particularly in distilled water (450–800 g/g), while showing reduced swelling in saline environments and pH-dependent behavior in acidic and alkaline media. The crosslinker content played a crucial role in determining the structural integrity and gel fraction of the hydrogels, with higher N,N′-methylenebisacrylamide concentrations leading to increased gel fraction but reduced swelling beyond an optimal level.

Soil application studies demonstrated that the incorporation of hydrogels significantly improved soil moisture retention, extending water availability by approximately 30–40% compared to untreated soil. As a result, irrigation frequency could be reduced without negatively affecting plant growth. Pot experiments further confirmed that the application of hydrogels enhanced plant biomass formation by up to 25–30%, indicating their positive impact on crop development under water-limited conditions.

Biodegradation tests revealed gradual mass loss of the hydrogels in soil, reaching 70–85% after 180 days, confirming their biodegradable nature and environmental compatibility. This characteristic distinguishes the developed hydrogels from conventional synthetic superabsorbent polymers and supports their suitability for sustainable agricultural applications.

Overall, cotton linter-based crosslinked biodegradable hydrogels represent a promising strategy for improving water use efficiency, mitigating drought stress, and enhancing agricultural productivity in arid and semi-arid regions. Future studies should focus on large-scale field trials, long-term soil impact assessments, and optimization of application rates for different crops and soil types.

The obtained results demonstrate that cotton linter–based biodegradable hydrogels can serve as promising soil conditioners for rainfed agriculture in arid regions such as the Aral Sea basin. Their application can contribute to improved water-use efficiency, mitigation of drought stress, and sustainable agricultural development in environmentally vulnerable regions.

The proposed hydrogel technology can contribute to sustainable land management and climate-resilient agriculture in drought-prone regions.

References

1. FAO. Water scarcity in agriculture. https://www.fao.org
2. Ahmed, E. M. *Hydrogel: Preparation, characterization, and applications*. J. Adv. Res., 2015. https://doi.org/10.1016/j.jare.2013.07.006
3. Guilherme, M. R. et al. *Superabsorbent hydrogels based on polysaccharides*. Eur. Polym. J., 2015. https://doi.org/10.1016/j.eurpolymj.2015.02.032
4. Montesano, F. F. et al. *Biodegradable superabsorbent hydrogel*. Agric. Water Manag., 2015.https://doi.org/10.1016/j.agwat.2014.10.010
5. Peppas, N. A. et al. *Hydrogels in biology and medicine*. Adv. Mater., 2006. https://doi.org/10.1002/adma.200501612
6. Rudzinski, W. E. et al. *Biodegradable polymers*. Polym. Degrad. Stab., 2002. https://doi.org/10.1016/S0141-3910(01)00208-3
7. Sannino, A. et al. *Water retention properties of hydrogels*. Polymer, 2009. https://doi.org/10.1016/j.polymer.2009.02.024
8. Thakur, V. K. et al. *Cellulose-based hydrogels*. Carbohydr. Polym., 2018. https://doi.org/10.1016/j.carbpol.2018.02.051
9. Zhou, Y. et al. *Cotton-based superabsorbent hydrogels*. Ind. Crops Prod., 2019. https://doi.org/10.1016/j.indcrop.2019.111530
10. Li, A. et al. *Graft polymerization on cotton cellulose*. J. Appl. Polym. Sci., 2017. https://doi.org/10.1002/app.45123
11. Zohuriaan-Mehr, M. J., Kabiri, K. *Superabsorbent polymer materials*. Iran. Polym. J., 2008. https://doi.org/10.1007/s13726-008-0001-1
12. Rashidzadeh, A. et al. *Crosslinker effect on swelling*. Polym. Adv. Technol., 2014. https://doi.org/10.1002/pat.3215
13. Dorraji, S. S. et al. *Superabsorbent hydrogels in agriculture*. Clean Soil Air Water, 2010. https://doi.org/10.1002/clen.200900204
14. Islam, M. R. et al. *Hydrogel application in crop production*. Agric. Water Manag., 2011. https://doi.org/10.1016/j.agwat.2010.09.003
15. Abobatta, W. F. *Hydrogel effect on cotton growth*. J. Plant Nutr., 2018. https://doi.org/10.1080/01904167.2018.1431674
16. Eshbo‘riyev T. N., Shirinov S. D. & Mamajanov M. M. (2026). “Conversion of PAN Fiber Waste into Water-Retaining Hydrogel for Agricultural Applications via Physical-Ionic Crosslinking.” Development Of Science, 1(7), pp. 183-195.