Application of Polymers for Sustainable Development in Agriculture: A Review

Ashok Bora[1]; Monidipa Dutta Borah[2]

[1,2]Department of Chemistry, Mariani College, Assam, India

Corresponding Author Email: ashokbora32@gmail.com

Abstract— Agriculture is a crucial sector for economic development of a country, as it generates employment, reduces poverty as well as provide food security for the people of a country. But as the population grows at an accelerated rate, demand for food production is also increased. In this regard, polymer researchers have developed a new kind of polymeric material that is hydrogel, to use as an alternative technique for conventional agricultural methods. Hydrogel can be used as a soil conditioner and controlled release system in agriculture which release water and fertilizer gradually to the plant for a long period. Herein, we reviewed the application of polymeric hydrogel in agricultural application and illustrating how they are practiced for sustainable development.

Keywords: Agriculture, fertilizer release, polymer, soil conditioner, sustainable practices.

1. INTRODUCTION

Agriculture is the science of cultivating crops and raising animals to provide food, fibre, fuel, and other essentials for human. The term agriculture is derived from two Latin words: agri, which means soil, and cultura, meaning cultivation [1]. It is the primary source of food for all countries, whether underdeveloped, developing or developed. It is an extremely important industry in any economy of the world [2]. It is a crucial sector that not only provides food security but also makes important contributions to employment, income generation, poverty reduction, and overall economic growth. Moreover, rapidly increasing world population also demands for high food production. Further, increasing agricultural production and productivity improve social welfare and living standard of rural areas. Therefore, increasing the food supply through the agricultural sector is crucial for a nation's economic development as well as to meet the global food demands. In this regard, use of larger quantities of water and fertilizer have been considered as the two most significant factors that influence the production of food. In order to enhance the agricultural productivity without expanding the cultivatable land, farmers are using a significant amount of fertilizer for cultivation. However, most of utilized fertilizer loss to surrounding via leaching, volatilization, and other processes [3]. As a result, it causes environmental pollution (water pollution, soil acidification, etc.), increases agricultural expenditures and waste of energy. On the other hand, water is another most essential elements for agriculture. However, access to adequate water for cultivation is becoming more challenging due to climate change, especially in water-scarce areas. Thus, there is an increasing demand for utilization of sustainable agricultural practices alternative to conventional ones. In order to solve these problems, utilization of highly swellable polymeric materials have been explored as an alternative irrigation technology [3,4]. Recently, polymeric hydrogels have become increasingly interesting material for the scientist due to their multifunctional properties [5]. Since their first practical implementation in 1960s, they have been using in various fields of applications including, agriculture, biomedical, energy storage, wastewater treatment and others [6]. Currently polymeric hydrogels have become a research hotspot in the field of agricultural application because of their high water swelling and retaining capacity as well as controlled release properties.

Hydrogels are three-dimensional polymeric material, able to absorb large amount of water and can retain for a long period of time within their network structure [7]. Based on their raw materials, they are categorized as biobased and synthetic-based hydrogels. Synthetic-based hydrogels are mainly produced from petroleum-based monomers including acrylic acid (AA), acrylamide (AM), acrylonitrile (AN), etc. [8]. Whereas, biobased hydrogels are prepared from copolymerization of polysaccharides (starch, guar gum, cellulose, etc.) with synthetic monomers [9]. Synthetic-based hydrogels possess higher swelling capacity, durability, mechanical strength compared to biobased hydrogels [10]. However, biobased hydrogels possess better biodegradability, biocompatibility, non-toxicity, and cost-effective nature. Additionally, they possess hydrophilic property due to the presence of various hydrophilic functional groups (such as hydroxyl, carboxyl, amino, etc.) in their network structure. Because of these properties, hydrogels are used as water reservoir in agriculture, which supplies water more efficiently to crops and can keep the soil moist for long period of time. Moreover, use of hydrogel also enhances the soil aeration, infiltration of water, microbial activity of soil and many others [11]. In order to increase fertilizer use efficiency and to reduce the effect of unused fertilizer on environment, hydrogels are used as controlled release system. They can be loaded with fertilizer via *in-situ* or *ex-situ* approach and released them to the plants in a controlled manner, which in turn reduces the loss of fertilizer by irrigation water or rain water as well as lowers the secondary environmental pollution [12].

Besides soil conditioner and controlled fertilizer release system, hydrogels are also used for soilless medium for cultivation [13]. They have been considered as effective material for soilless cultivation due to their ability to absorb and store significant amount of water. Unlike traditional soil-based cultivation, this method does not involve any soil- and water-related problems. Moreover, this method also reduces the labor requirements [14]. Thus, application of polymeric hydrogel can be considered as potential for sustainable agricultural practices in water-scarce areas. In this regard, researchers have been continuously exploring polymeric hydrogel to meet the global food demands while reducing the expenditure of the material and its adverse impacts on the environment. Herein, our primary objective is to study the utilization of polymeric hydrogel in agriculture. Secondly, to find out whether or not utilization of hydrogels could be favorable for sustainable agricultural practices.

2. METHODOLOGY

Herein, a thorough literature review on available scientific reports have been carried out. Electronic research of published papers were conducted using Google Scholar, Web of Science and PubMed until April, 2024. The following keywords were used while searching the literature: polymer, hydrogel, agricultural application, soil conditioner, controlled release fertilizer, sustainable agricultural practices, etc.

3. REVIEW OF LITERATURE

In the last few years, utilization of polymeric hydrogels in agriculture have gained considerable attention from both researchers and farmers. Many reports regarding the utilization of polymeric hydrogels have been reported in the literature. For instance, Sayed et al. investigated guar gum, pectin and polyacrylamide-based hydrogel for sustainable agriculture in 2022 [15]. The prepared hydrogel was cross-linked with gamma irradiation (10kGy). The results indicate that water holding capacity (66%) and water retention (15%) was observed after 20 days of incubation. Moreover, a high-water swelling capacity (1050 g/g) and good biodegradable properties were also observed for the synthesized material. In another work, Zhang et al. developed AA-based hydrogel for controlled release of urea [16]. They achieved slow urea release behavior (release only 3.71% of loaded nutrient after incubated for 40 days in water) and excellent water swelling capacity (909 g/g of the dry hydrogel) for the prepared hydrogel. Further, they observed pronounced effect of the urea-loaded hydrogel on maize germination. Addition of only 0.2% of the prepared hydrogel promoted seedling height and root length of maize. In 2020, Wang et al. developed low cost and environmentally hydrogel for water retention in agricultural application [17]. The hydrogel was prepared by cross-linking of fenugreek galactomannan with borax using one step synthesis method. This method is considered as rapid, economical, efficient and convenient for large scale production of hydrogel. They observed an increased swelling index and water retention of sandy soil after addition of the prepared hydrogel. In another work, She et al. fabricated a hydrogel by cross-linking sodium alginate, lignosulfonate, konjaku flour and studied its effect on water holding and retention capacity of soil [18]. Further, they evaluated its performance on tobacco plants under drought condition. A higher water swelling capacity of 41 g/g was observed for the hydrogel. Moreover, an increased water holding capacity and reduced nutrients leaching from soil was also observed due to the utilization of the applied hydrogel. Further, it was found that this hydrogel could be able to improve the photosynthetic capability of tobacco plants under drought stress condition. In another work, Marin et al. designed chitosan and salicylaldehyde-based hydrogel to use as soil conditioner and for controlled release of urea [19]. The results showed that prepared hydrogel possess water swelling capacity of 68 g/g and enhanced the water holding capacity of soil up to 154%. Moreover, addition of the hydrogel almost doubled the nitrogen content in the soil which in turn leads to the growth of tomato seedlings with 70% higher in comparison to untreated soil. In 2024, Sujith et al. developed polyvinyl alcohol and soy-protein-based an ecofriendly hydrogel for controlled release of urea [20]. The report showed that release of 74% of encapsulated urea from the hydrogel was observed after 28 days of incubation, which indicates the controlled release property of the synthesized hydrogel. Moreover, water retention study indicated that it can be used as a good soil conditioner for water-scarce area as it could retain the absorbed water up to 30 days. Further, the prepared material could improve the growth performance of amaranthus and pea seedlings Thus, it can be said that the polymeric hydrogels can be regarded as an excellent candidate for sustainable agricultural practices.

4. DISCUSSION

After going through an extensive literature survey, we have come to know that hydrogels have various advantageous properties including water-holding as well as retaining ability, ecofriendly, affordability, non-toxicity and controlled release properties, which make them suitable for agricultural applications [20]. Since, hydrogels are found to be able to absorb water up to 1000-100000 percentage to their dry weights, they can be used as an excellent soil conditioner for water-scarce area [21]. Thus, mixing of hydrogels can improves the physical, chemical and biological properties of soil. Due to the addition of hydrogel, soil can retain higher amount of water and release them gradually in to soil under drought condition [22]. Further, it promotes seed germination rate, seedling growth, root growth, and crop productivity [23]. Moreover, use of hydrogel as a controlled release system enhances the nutrient use efficiency by reducing the leaching of fertilizer [24]. As a result, it can contribute to the prevention of pollution. Thus, polymeric hydrogels may become a sustainable agricultural practice in water-scarce areas.

5. CONCLUSION

It is known that aim of sustainable agriculture is to utilize novel technology that leads to meet the global food demand while maintaining the environment and reducing the cost [20]. In this regard, polymeric hydrogels have been used as soil conditioner and controlled fertilizer release system, which improves the water as well as fertilizer use efficiencies of soil. Moreover, it reduces the leaching of fertilizer which in turn results in lowering of environmental problems. Also, it can save time, reduces expenditure and labor requirements because there need only one application. Therefore, utilization of polymeric hydrogels can be considered as an excellent material for sustainable agricultural practice in arid and semi-arid regions.

REFERENCES

1. Rao V. P., Veeraraghavaiah, R., Hemalatha S., and Joseph B. Farming systems and sustainable agriculture, 2010.
2. Yusuf S. A. Role of agriculture in economic growth and development: Nigeria perspective, 2014.
3. Chen L., Liu X., Hua Z., Xue H., Mei S., Wang P., and Wang S. Comparison of nitrogen loss weight in ammonia volatilization, runoff, and leaching between common and slow-release fertilizer in paddy field. Water Air Soil Pollut., 232, pp. 1-11, 2021.
4. Pushpamalar J., Langford S. J., Ahmad M. B., Lim Y. Y., and Hashim K. Eco-friendly smart hydrogels for soil conditioning and sustain release fertilizer, Int. J. Environ. Sci. Technol., 15, pp. 2059-2074, 2018.
5. Patra S. K., Poddar R., Brestic M., Acharjee P. U., Bhattacharya P., Sengupta S., and Hossain A. Prospects of hydrogels in agriculture for enhancing crop and water productivity under water deficit condition, Int. J. Polym. Sci., 2022.
6. Lee S. C., Kwon I. K., and Park K. Hydrogels for delivery of bioactive agents: a historical perspective. Adv. drug deliv. Rev., 65(1), pp. 17-20, 2013.
7. Zhao S., An X., An W., Hu J., Wu P., and Cui W. Efficient adsorption of anionic and cationic dyes by PVA/PAA/GO composite hydrogel with three-dimensional porous double network structure. Mater. Chem. Phys., 313, pp. 128716, 2024.
8. Harun-Ur-Rashid M., and Imran A. B. Superabsorbent hydrogels from carboxymethyl cellulose. Carboxymethyl Cellulose, 1, pp. 159-182, 2019.
9. Mittal H., Ray S. S., and Okamoto M. Recent progress on the design and applications of polysaccharide-based graft copolymer hydrogels as adsorbents for wastewater purification, Macromol. Mater. Eng., 301(5), pp. 496-522, 2016.
10. Ahmed E. M. Hydrogel: Preparation, characterization, and applications: A review, J. Adv. Res., 6(2), pp. 105-121, 2016.
11. Shubhadarshi S., and Kukreja S. Hydrogel: Promising alternative for water and nutrient management, Int. J. Chem. Stud., 8(6), pp. 354-358, 2020.
12. Liu Y., Wang J., Chen H., and Cheng D. Environmentally friendly hydrogel: A review of classification, preparation and application in agriculture, Sci.Total Env., 846, pp.157303, 2022.
13. Huang Y., Chang Y., Ni Z., and Wang L. Environmental parameters factors exploration on lettuce seed germination with hydrogel. Front. Plant Sci., 15, pp. 1308553, 2024.
14. Sayed A., Mohamed M.M., and Abdel-raouf M.E.S. Radiation Synthesis of Green Nanoarchitectonics of Guar Gum-Pectin/Polyacrylamide/Zinc Oxide Superabsorbent Hydrogel for Sustainable Agriculture, J. Inorg. Organomet. Polym., 32, pp. 4589–4600, 2022.
15. Cheng D., Liu Y., Yang G., and Zhang A. 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, J. Agric. Food Chem., 66(23), pp. 5762-5769, 2018.
16. Liu C., Lei F., Li P., Jiang J., and Wang K. Borax crosslinked fenugreek galactomannan hydrogel as potential water-retaining agent in agriculture, Carbohydr. Polym., 236, pp. 116100, 2020.
17. Song B., Liang H., Sun R., Peng P., Jiang Y., and She D. Hydrogel synthesis based on lignin/sodium alginate and application in agriculture, Int. J. Biol. Macromol., 144, pp. 219-230, 2020.
18. Iftime M. M., Ailiesei G. L., Ungureanu E., and Marin L. Designing chitosan based eco-friendly multifunctional soil conditioner systems with urea-controlled release and water retention, Carbohydr.e Polym., 223, pp. 115040, 2019.
19. Ashok K. A., Saeed P. A., Manholi S., and Sujith A. Polyvinyl alcohol-soy protein isolate hydrogels: Controlled release of fertilizer and matrix nutrients for sustainable agriculture, J. Clean. Prod., pp. 141827, 2024.
20. Varaprasad K., Raghavendra G. M., Jayaramudu T., Yallapu M. M., and Sadiku R. A mini review on hydrogels classification and recent developments in miscellaneous applications, Mater. Sci. Eng. C, 79, pp. 958-971, 2017.
21. Saha A., Sekharan S., and Manna U. Superabsorbent hydrogel (SAH) as a soil amendment for drought management: A review, Soil Tillage Res., 204, pp. 104736, 2020.
22. Zhang H., Yang M., Luan Q., Tang H., Huang F., Xiang X., and Bao Y. Cellulose anionic hydrogels based on cellulose nanofibers as natural stimulants for seed germination and seedling growth, J. Agric. Food Chem., 65(19), pp. 3785-3791, 2017.

23. Nissen T. M., and Wander M. M. Management and soil-quality effects on fertilizer-use efficiency and leaching, Soil Sci. Soc. Am. J., 67(5), pp. 1524-1532, 2003.