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Biodegradable hydrogel materials for water storage in agriculture - review of recent research

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ABSTRACT

The aim of the study was to indicate the potential application of superabsorbent hydrogels as water reservoirs, as well as macro and microelement carriers, for the use of watering and fertilization of arable lands in the context of hydrological drought. A review of the latest research on biodegradable structures used in agriculture is presented. Hydrogels composed of natural polymer materials can absorb water from precipitation and gradually release it into the soil during drought. They are therefore a buffering factor increasing the water capacity of soils. The application of biodegradable biopolymer hydrogels reduces the frequency of land irrigation, increases the soil's ability to infiltrate and retain water and meets basic environmental protection requirements. The use of superabsorbent hydrogels in agriculture leads to water resources saving. According to the concept of sustainable development, biopolymer hydrogels, which are environmentally friendly, have considerable potential for being used as a reservoir of water and fertilizer nutrients in the agricultural sector. Synthetic hydrogels based on acrylates and acrylamides show high mechanical strength and the potential to absorb significant quantities of water. Due to the problem of their biodegradability, they are being attempted to replace with biopolymers such as alginate, agar, cellulose, chitosan, and starch. Biocapsule from natural materials can serve as a water storage, but also as macro- and micro-elements carriers for precise fertilization.

Keywords: Hydrogel; Soil moisture; Water holding capacity; Superabsorbent; Drought

1. Introduction

The most drought-sensitive sector of the economy is agriculture. High temperatures and low soil moisture disturb the proper plant's growth, leading to a reduction in the quantity and quality of crops. The problem also concerns water shortages in cultivated fields.

Direct watering the crop surface is a commonly used irrigation method, which does not solve the problem of drought. As a result of evaporation or run-off, a significant amount of water is lost and plants suffer for water shortage, which results in reduced crop yields. The use of sprinklers reduces water losses but requires the purchase of expensive equipment that most farmers cannot afford. Additionally, the costs of water itself is high. In the current global ecological

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and economic situation, the demand for water is constantly growing, but the availability of clean freshwater water is permanently decreasing. The effect of hydrological drought on agriculture is a global problem and forces to search for new solutions. One of the temporary methods is the use of hydrogel materials with good water absorption and retention properties, even at high temperatures [1]. As a hydrophilic polymer, it has great potential for soil regeneration and restoration. Superabsorbent water and other liquid polymer hydrogels can affect soil permeability, density, structure, texture, evaporation, and soil water infiltration rate. Properly selected hydrogel for a given nutrient can maintain about 95% of the absorbed water available for plants [2]. Hydrogel polymers are highly crosslinked and can absorb and retain a significant amount of water or other liquids (retention can reach up to 1 kg of liquid per gram of hydrogel).

Nevertheless, materials used in the production of hydrogel must meet high environmental safety demands, For example, be biodegradable, not-phytotoxic, and not negatively affect the environment [3]. Superabsorbent polymers (SAPs) are divided into synthetic and natural polymers. The first is often made from acrylic acid, its salts or acrylamide; by means of solution or inverse suspension polymerization techniques. Although such hydrogel polymers have high water uptake capacity, their wide use is strongly limited by their low biodegradability and high costs. Nevertheless, it is also possible to synthesize hydrogel polymers based on biological materials prepared, for example, from cellulose, starch, carrageenan, gelatin, chitosan, rapeseed protein, alginate, and collagen [4].

2. Drought and its impact on agriculture

2.1. Drought

The problem of drought, occurring permanently or periodically, is present almost in all parts of the world. It is associated with a long-term reduction of the balance between the average amount of precipitation and the evaporation of water in the examined area. However, this is not the only parameter that should be considered, especially in a dry climate. It is difficult to determine how disastrous a drought is and its long-term impact on an area. This depends not only on the duration of the drought (which is possible to estimate after its end), intensity and geographic location. Drought and its consequences have an impact on society, the economy, and the environment [5].

Also, drought causes a decrease in drinking water resources, an increase in the risk of fires and dryness of the soil. The persistent lack of precipitation seriously disturbs the hydrological conditions of the soil. The first stage of the phenomenon is the atmospheric drought. The long-term predominance of the amount of evaporating water over the amount of water supplied from the atmosphere results in soil drought. In the last stage, there are drops in water levels and flows of rivers, and even drying of smaller water reservoirs (hydrological drought) [6].

The hydrological drought is a serious threat to the ecosystem and society, which is associated with desertification and water shortages in many regions of the world. The type of climate in a given area (e.g., a climate with high seasonality) has a direct impact on the progress of hydrological drought. In regions with relatively constant weather conditions, drought occurs when rainfall is below normal. In contrast, the seasonal climate is characterized by summer and winter droughts, which determine the lack of rainfall in the rainy season. It occurs on the savannah, monsoonal, and in the Mediterranean climate [7].

2.2. Effect of drought on agriculture

Agriculture is the sector that uses most of the water resources and is also the most vulnerable to water shortages. The degree of implementation of rules of sustainable development in agriculture is low. Water consumption is inefficient, which is supported by the low effectiveness of plant irrigation comparing to the amount of water used for these purposes [8]. Water is becoming a scarce resource, less available, and more needed at the same time. The predicted rise of temperature on our planet is a warning and predicts rapid changes not only in climate but consequently in the cultivation of crops [9].

The definition of drought in agriculture combines the characteristics of meteorological drought (associated with a reduction in rainfall and thus in soil moisture) and has an impact on agriculture. In the continental area, summer precipitation is strongly dependent on the amount of water evaporating from the soil, which depends on its moisture content. Both temperature and humidity of the soil have a direct impact on its elemental composition, mineralization of nutrients, and release of gases into the atmosphere. The climate change that we are experiencing results in a long-term transformation of soil composition, microflora, and structure, which also affects the quality of yields in the area. Lower soil moisture can slow down the decomposition of organic matter and therefore promote an increase of carbon content in the soil [10]. The rise of temperature also results in an increase in soil salinity, which has an impact on the osmotic balance of the soil-plant system and nutrient uptake by the roots.

Drought is one of the factors that have the strongest effect on plants. Plant demand for water is fluctuating and depends on crop type and geographical latitude. The sensitivity of plants to various unfavorable environmental factors depends on the growth phase of the plant. The lower soil moisture content at an early stage of plant cultivation will be more important for growth than at a later stage. Lack of moisture during cultivation causes a decrease in productivity [11].

Osmotic stress is the first reaction of plants to drought or increased salinity; its presence causes many adaptive changes in plants, allowing them to survive short-term adverse environmental changes [12]. Plants react to short-term water stress by reducing the gas exchange. When stress caused by abiotic factors is prolonged, oxidative stress occurs, which interferes with cellular metabolism, cellular process disorders, including inhibition of enzymatic reactions. This results in the inhibition of plant growth, disruption of all metabolic processes, and can also lead to death [13].

3. Hydrogels for water storage

Hydrogels are networks of natural or synthetic polymer chains, which in some cases can be considered colloidal gels, in which water is a dispersing medium. They are water-absorbing natural or synthetic polymers (swollen polymers may contain over 99% water). Hydrogel forming polymers never dissolve in water, and their polymer chains are spatially bonded with covalent bonds. Hydrogels are materials that can swell in water and retain a significant fraction of water in their structure (about 20%), without dissolving in water. As a result of the high water content, these materials have a high degree of flexibility, which is very similar to natural tissue [14].

Hydrogels have a positive effect on the physical properties of the soil—increase the water retention capacity and infiltration, minimize the need for frequent watering. These structures can absorb rainwater and store it inside a network of hydrophilic polymer chains. The application of hydrogels in the soil causes that the water is gradually released into the soil and plant roots can absorb it slowly, and thus longer-term quantities of water can be provided. The hydrogel dose must be adapted to the soil conditions.

Particular attention has recently been paid to the potential use of hydrogels in agriculture. Their properties making them a good solution for some environmental issues, started lively discussions not only among researchers and scientists but also among commercial companies and policymakers [15].

3.1. Classification of hydrogels

Hydrogels can be classified based on various parameters, which are shown in Fig. 1. The properties of hydrogels depend on their structure, degree of crosslinking, as well as on water content and state. Water in the hydrogel matrix may be in non-bound—free form (NBW), strongly bound to the polymer chain (SBW) and in weakly bound form (WBW). The determinant of the category of water state is the phase change that occurs under certain conditions. In the case of NBW, water freezes at 0 degrees, i.e., similarly to water outside the structure, weakly bound (WBW) at temperatures below 0°C, while strongly bound doesn't change in the temperature range of –70°C to 0°C. The study of the water state is particularly important from an agricultural application point of view, because it enables, among others, analysis of nutrients diffusion and sorption properties of hydrogels [16].

The basic criterion for the classification of hydrogels is their origin. There are two main types: synthetic and natural. Synthetic hydrogels (hydrophilic polymers) are a class of special gels, created by chemical stabilization of hydrophilic polymeric materials in a three-dimensional network, while natural consists of polysaccharides having the ability to create a hydrophilic chemical structure with high biocompatibility. Most of the traditional hydrogels available on the market are acrylate-based products. The type of crosslinking agent used in chemical polymerization methods strengthens the bonds between polymer chains. Thus, these materials are not biodegradable or have a much lower degree of degradation compared to their natural counterparts. In this case, in many environments, these materials can be considered a threat to potential soil contamination. In view of the growing interest in environmental issues, hydrogels that are biodegradable, do not lead to soil degradation nor pose phytotoxicity and are environmentally safe [17–19].

3.2. Hydrogel structure

The main property of hydrogels is the capability to absorb and store large amounts of liquids that far exceed their dry matter. Water absorption by the hydrogel causes a significant

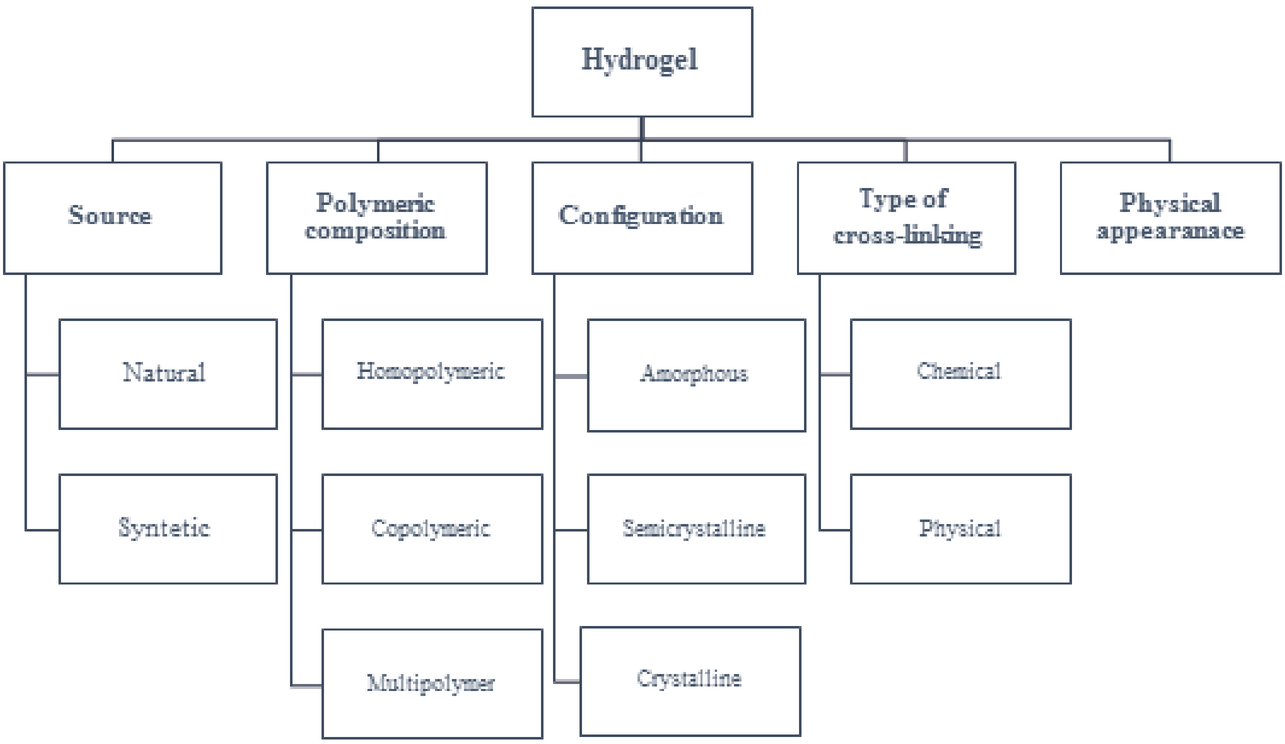

Fig. 1. Classification of hydrogels.

increase in their volume without dissolution of the polymer matrix. In a dry environment, water can be released slowly from the structure of hydrogels into the environment—for example, soil with low humidity. Hydrogels are hydrophilic polymers, macromolecular compounds that create three-dimensional networks. Hydrogels in the dry state are often in the form of coiled polymer beams, which under the influence of water are gradually loosened and elongated [15].

The absorption process is complete when the hydrogel reaches its maximum swelling level and can no longer absorb water. In most cases, the release of water from the hydrogels is caused by a significant difference in humidity between the hydrogel and the medium in which it is located. The structure of hydrogels and functional groups that makes up its structure can affect the behavior and mechanism of absorption and release of water from the volume of hydrogels [20]. A distinction should be made between hydrosols and hydrogels, with the first indicating solutions in which the polymers were dissolved in water. The latter, through the appearance of chemical or physical crosslinks (connections, bonding points, and entanglement) (Table 1) in the polymer network, are not able to dissolve in water but can absorb it, increasing their volume.

The system created in this way is very complex and can be considered to be composed of three different parts: a solid matrix of a polymer network, interstitial water or biological fluid and various types of ions. This behavior of the system is the result of the interaction of all these three parts with the external environment. Water absorption due to the difference in osmotic pressure causes the network to swell. Chains between network intersections are required to adopt elongated configurations generating elastic force. As it swells, this force increases and the dilution force decreases. Ultimately, an equilibrium swelling state is reached in which the two forces are in equilibrium with each other [20].

In the case of polymers having an ion network with ionizing groups, the swelling ability can be significantly increased due to the existence of charges causing electrostatic repulsion. The system, therefore, tends to expand its network. However, the determined charges are not only related with the ions present in the gel; at least the stoichiometric number of moving counter ions should also be taken into account.

All these characteristics make hydrogels useful materials for many technologies. Due to this structure, the hydrogels can respond to parameters, such as temperature, pH, and changes of dissolved substances [15].

3.3. Mechanism of water absorption and release

Water absorption and release in hydrogels are determined by at least two factors: hydrogel's free volume (e.g., macroporosity and interconnectivity of macropores) and obstruction effects of the polymer matrix. The process consists of three stages (Fig. 2): (1) migration of rainfall water from soil into the hydrogel, (2) increase of the pressure inside the capsule due to water storage, and (3) release of water into the soil (3). The key factors of the process are the type of coating polymer and its thickness [20].

Since the polymer structure is a three-dimensional hydrophilic matrix, it is common to approximate hydrogel as organic tissue. In this case, the internal diffusion of water into the membrane or its release can be considered as the rate-limiting step of the process kinetics. Thus, assuming that immersion of hydrogel into water proceeds according to the Fick's law and Eq. (1) holds for relatively short time t, corresponding to $m_t/m_\infty < 0{,}5$, the Fick's equation is expressed as follows:

$$\frac{m_t}{m_\infty} = 4\left(\frac{D \cdot t}{\pi \cdot l^2}\right)^{1/2} \tag{1}$$

where m_t and m_∞ are the mass increments at a given time and in a state of equilibrium, respectively; l is the thickness of the material and D the is the diffusion coefficient. The maximum water content is calculated by measuring the mass of the sample as a function of the time from dry to swollen condition [21]. In accordance with Eq. (1), the kinetics of the water release is not dependent on the geometry of the device. Nevertheless, since water requires polymer chains to be separated for the network structure permeation, D value can increase with crosslinking density. For a short diffusion time, considering non-swelling or dissolvable membrane, the release of water can be characterized by first-order kinetics. If swelling polymers diffusivities are strongly dependent on the swelling degree and density of the polymer, the value of D is strongly influenced by environmental changes or degradation of the polymer matrix.

The division of models currently applied for a mathematical description of water release is depicted in Fig. 3. They consider either diffusion or a combination of relaxation and diffusion [22]. The majority of mathematical models assume ideal conditions and do not account for polymer degeneration. The most commonly used equations are presented below.

Table 1
Examples of various ions found in natural hydrogel-forming polymers

Polymer	Functional group	Type of crosslinking
Gelatin	$–COOH, –NH_2, –OH$	ionic, chemical
Alginate	$–COOH, –OH$	ionic, chemical
Carboxymethyl cellulose	$–COOH, –OH$	ionic, chemical
Chitosan	$–NH_2, –OH$	ionic, chemical
Fibrin		covalent
Silk fibroin	$–COOH, –NH_2$	sol-gel transition
Agarose	$–OH$	coil-helix transition

In 1961, Higuchi [23] proposed a theoretical approach based on the following assumptions: diffusion of water proceeds in one dimension and under constant rate, matrix water particles are smaller than hydrogel thickens, and perfect sink conditions are achieved in the environment, while swelling is negligible. This model is represented by the equation:

$$\frac{m_t}{m_\infty} = \left[D \cdot t \cdot C_s\left(2C - C_s\right)\right]^{1/2} \quad (2)$$

where C and C_s is the initial water content and solubility in hydrogel media, respectively. This relation is based on Fick's law and is time-dependent. It may be used for modeling the kinetics of swelling, as well as for water releasing [24].

The Korsmeyer–Peppas semi-empirical model is expressed by the Eq. (3) [25]:

$$\frac{m_t}{m_\infty} = k \cdot t^n \quad (3)$$

An important utility of the model results from the fact that the main mechanism can be estimated based on the value of the parameter n: either the Fick's diffusion or the polymer relaxation-driven swelling. For n = 0.5 the Fick's diffusion occurs, while for 0.5 < n < 1 there is non-Fick's diffusion. In some cases, an anomalous transport mechanism, the type of intermediate transport, is involved [21].

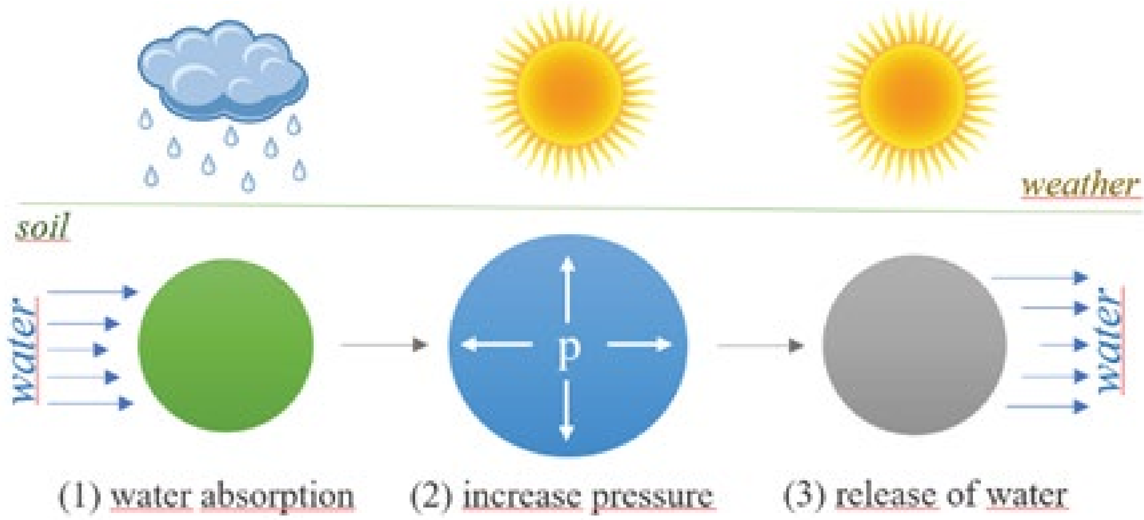

Fig. 2. Mechanism of water absorption in hydrogels.

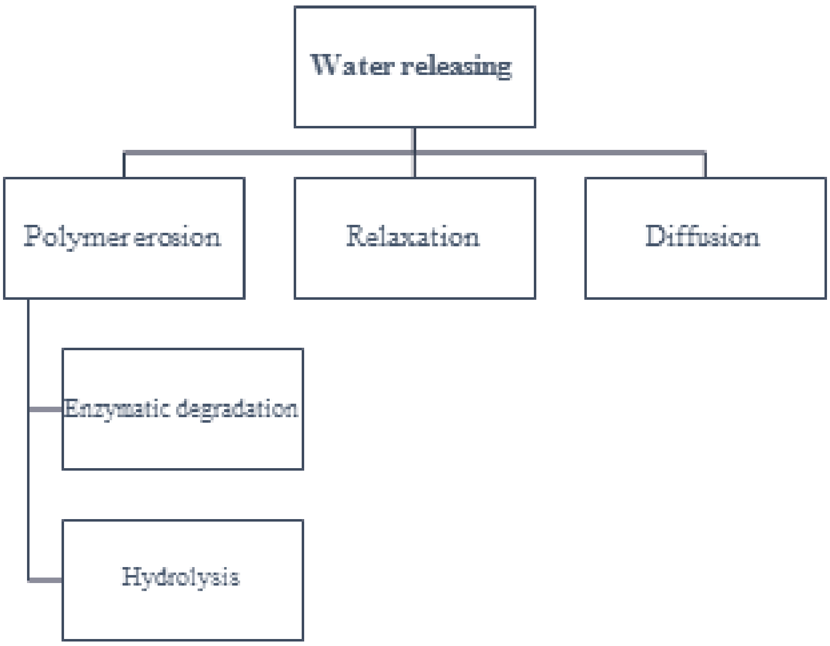

Fig. 3. Models for water release from hydrogel capsules.

The Weibull model and its adaptation to the swelling/releasing processes can represent release kinetics in any heterogeneous matrices [26]. It is an empirical model that does not assume any kinetic mechanism. The model is given by:

$$\frac{m_t}{m_\infty} = 1 - e^{-\alpha t^\beta} \quad (4)$$

where: α is a "scale factor" and β is a "shape factor".

The validity of the above models has been investigated by many researchers [27–29]. However, the models' assumptions have not sufficiently been experimentally validated, yet. This is caused mainly by an unclear structure that results from their inherent heterogeneity.

4. Collection of SAPs

Precipitation significantly affects the quantity and quality of crops. Insufficient rainfall generates significant losses in the agricultural sector. Plant stress resulting from water shortage can lead to a decrease in chlorophyll content or a lower yield of seeds, flowers or fruits. Water scarcity is a serious global problem that is further aggravated by climate change. Crop irrigation is expensive, especially in drought-affected areas [30]. The solution to these problems may be SAPs, which could act as "water reservoirs". These materials are polymer networks with a low degree of crosslinking, thanks to which they can absorb and store large amounts of water (up to 1,000 times the weight of the polymer) [31]. The osmotic pressure difference causes water transport from the soil to the SAP hydrogel. When the soil dries, the stored water is slowly released, maintaining moisture. What is more, the swelling of the hydrogel increases the porosity of the soil so that they are better aerated [32].

So far, SAP materials used in agriculture are acrylates and acrylamides derived from petrochemical products. The implementation of SAP hydrogel technology is one of the methods to save water and money in agriculture. In addition to maintaining soil moisture, the use of synthetic hydrogels reduces the use of pesticides and leaching of fertilizer nutrients. Despite many beneficial properties, synthetic hydrogels are not biodegradable. Considering the need to protect the environment, biopolymer materials are becoming more popular, including natural and readily available polysaccharides such as chitosan, alginate, cellulose, or starch, etc. The production of synthetic polymers is more expensive than natural polymers [33]. Fig. 4 shows the benefits of using SAP hydrogels [30]. They have a beneficial effect on soil structure and its permeability-increasing soil aeration, microbial activity, and reducing the frequency of irrigation. The slow release of water during the drought retards the wilting of plants. The improvement of soil water retention and water supply of plants promotes efficient and productive agriculture [32].

The polymerization and crosslinking method influence the physicochemical properties of the obtained polymers (mechanical properties and water storage capacity). Synthetic SAPs are more resistant to damage and degradation of the hydrogel structure than biopolymers. This means that biopolymers are not commonly used as hydrogels for water storage (sensitive to storage conditions, modification needed to create a durable SAP hydrogel). To ensure adequate strength and biodegradability of structures, hydrogels are formed consisting of synthetic and natural polymers [31]. Technology based on SAP materials is a promising way for sustainable use of decreasing water resources in agriculture. Choosing the right polymer material to create hydrogel "water storage" will allow obtaining photostable structures with a neutral pH, which can be repeatedly used to maintain soil moisture [34].

5. Latest research on biodegradable hydrogel materials for water storage in agriculture

Superabsorbing polymers are polymers with the capacity to absorb and retain water hundreds of times greater than their weight. The presence and availability of hydrophilic groups ($-SO_3H$, $-OH$, $-CONH$, and $-CONH_2$) determine these properties. The possibility of water absorption and retention causes that these types of materials have been used in many commercial hygiene or pharmacy products, but also as soil conditioners. The latest application can be one of many solutions to the problem of drought, which largely affects

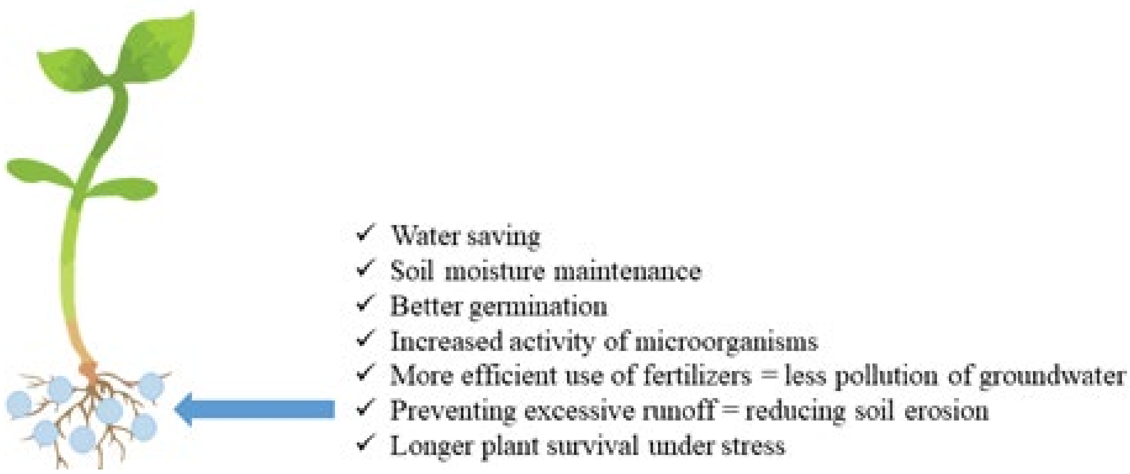

Fig. 4. Advantages of SAP hydrogels in agriculture.

agriculture. Recent research mainly concerns the possibility of reducing production costs, biodegradability but also the ability to increase the absorption capacity of the produced water storage facilities [35].

Ye et al. [36] presented the possibility of using the waste from the paper industry and acrylic acid to produce hydrogel possessing water storage properties. Composites were prepared by copolymerization of red liquor and acrylic acid. The use of red liquor without pre-treatment has been presented, which allows minimizing the costs of waste utilization. The composites achieved an absorption capacity of 280 g/g. In addition, the properties allowing for slower water release were obtained. The retention factor was 80% at 50°C for 24 h. The presented hydrogels, due to their properties, may find potential applications for cereals, fruits, and vegetable cultivation as the remedy for drought.

Heise et al. [37] proposed the possibility of producing hydrogels based on wheat straw and lignocellulose matrix as structures improving soil quality. A non-toxic citric acid was used as the cross-linking agent. The swelling ration of the produced structures was examined and equaled 50 g/g. Experiments have shown that the application of hydrogels to sandy soil (0.2 wt.%) increased the soil water capacity by 70%.

Rop et al. [38] demonstrated the possibility of using extracted cellulose from water hyacinth, acrylic acid, and acrylamide for the synthesis of polymer hydrogel. The highest water absorption capacity was found to be 165 g/g. Water retention capacity in sandy loam soil was also tested using 1.5 wt.% copolymer. The moisture content of the soil increased by about 30%. The degradation of cellulose grafted copolymer in soil was also investigated. After two weeks, weight loss was found to be 25%. It was found that the copolymers showed a very good ability to absorb and retain water in the soil, were biodegradable and could be used in the agricultural industry.

Hybrid hydrogels based on corn starch modified with microgel latex were prepared by Amiri et al. [39]. To increase the strength of the hydrogel, surface treatment was carried out with 3-propyl-trimethoxysilane. The maximum water absorption capacity was 87 and 77 g for structures without surface treatment and after surface treatment, respectively. Studies were also carried out on the swelling of structures in NaCl solution 0.9 wt.%, which was 25 and 21 g/g, respectively.

Tanan et al. [40] demonstrated that hydrogels made from starch-g-polyacrylic acid, natural rubber, and polyvinyl alcohol blends. The synthesis was carried out using ammonium persulfate, and N,N′-methylene bis-acrylamide as the cross-linking agent. Studies related to swelling in water and in NaCl solution 0.9 wt.% were carried out. The polymer with optimal composition achieved swelling ratio of 794% and 244% for water and salt solution, respectively. The soil biodegradation experiment was conducted for 120 d and the biodegradation rate was estimated as 0.626% mass/d. It was found that the produced hydrogel structures can be used in the agricultural sector due to the very good water storage capacity.

The use of water carriers of natural origin is of great importance in the chemical industry. Hydrogels from natural polysaccharides (acacia, cellulose, or starch) are environmentally friendly and their biodegradation is much easier and quicker. Hasija et al. [41] presented the possibility of producing a superabsorbent based on agar and arabic gum. It was found that the Hashiarpur soil with the produced hydrogels maintained its humidity for 13 d longer. A study was also conducted on the biodegradation of samples, where it was found that the largest biodegradation potential is found in soil microorganisms.

Many recent works also focus on innovative solutions for the production of synthetic or semi-synthetic hydrogels. Xiao et al. [42] prepared superabsorbent, biodegradable hydrogels from acrylic acid and acrylamide based on the new crosslinking agent. The cross-linking agent was prepared by mixing polycaprolactone, polyethylene glycol isophorone diisocyanate, and dibutyltin dilaurate at 80°C. After cooling the polymer, hydroxyethyl acrylate was added. Superabsorbents achieved a high absorption capacity of 875 g/g. Also, the absorbency of other aqueous solutions was tested. The absorbency for a NaCl solution 1 wt.% was 71 g/g. The biodegradability of superabsorbents in phosphate buffered solution was also investigated. The study was conducted for 30 d at a temperature of 37°C. Most of the hydrogels dissolve in the solution. Presented superabsorbents could be useful in the agricultural and hygiene sector as super-absorbent materials in children's pampers or feminine hygiene products.

Saruchi et al. [43] described the synthesis of polymer networks catalyzed by lipase enzymes to produce superabsorbent hydrogels. Tragacanth gum, acrylamide, and methacrylic acid were used to make the composites. The produced hydrogels increased the water retention capacity in clay and sandy soils by about 8%. Biodegradation of produced structures by composting and soil-burial method was also examined. The study was conducted for 77 d and during the composting 100% degradation was obtained, while in the soil hydrogels were degraded in 81%. The potential use of hydrogels in elements delivery has also been investigated. The research was carried out on urea and calcium nitrate. After 44 h of testing, calcium nitrate release was 37% and urea 58%. It was found that the synthesized composite can be used in the agricultural sector.

Alam and Christopher [44] proposed the production of superabsorbent hydrogels consisting of two biopolymers, cellulose aldehyde, and chitosan. Water retention studies were carried out for water and salt solution, also in the presence of ammonium or potassium cations in the solutions. The maximum absorption capacity was 610, 85, 96, and 91 g/g, for four media, respectively. The research related to the reuse of hydrogels has shown that after four cycles, the composites have lost 5%–10% water retention.

Hydrogels, due to their properties, can also be used as carriers of macro- and micro-elements, and at the same time can have the function of water storage. Calcagnile et al. [45] in their work presented a composite material with high salt solution absorption and retention capacity as well as controlled release of fertilizers. Cellulose was used as the main component. Polylactic acid (PLA) was added to the final composition to provide a slowed release. Potassium nitrate was used as the salt solution. A comparison was made of the salt solution absorption capacity of two types of hydrogels: containing PLA and those consisting of cellulose alone. The absorption capacity of the salt solution was 140 and 70 g/g, for composites of cellulose and composites with the addition of PLA, respectively. It was investigated that structures made of cellulose released more than 90% salt solution after 6 h, while PLA composites released about 80% salt solution after 168 h. It has been found that PLA-containing composites have lower ability to absorb salt solution, but can release it more slowly, which is a positive effect in this case.

Skrzypczak et al. [46] presented the possibility of using composites composed of sodium alginate, carboxymethyl cellulose, and eggshells as a material with controlled copper (II) ions release properties. Hydrogel swelling tests were performed, among others in $NaNO_3$ solution 1 wt.%, which amounted to 180 wt.%. Microelement release tests were also carried out. During 14 d, the release of copper (II) ions was 9 wt.%.

A review of recent research shows that there is a strong demand for cheap, environmentally friendly superabsorbents. One of the options could be the use of biopolymers. They are easily available and can be derived from waste biomass (alginate, cellulose, or starch), which can significantly reduce raw material costs. Moreover, the decrease of synthetic materials content in polymeric matrix, or their complete elimination, is beneficial for both environmental and economic aspects. Last but not least, concerning hydrogels water storage properties, they can also be used as fertilizer carriers with controlled release of nutrients.

6. Conclusion

The progressive increase in hydrological drought and long-standing actions leading to environmental degradation on the part of the plant growing sector are among the major socio-economic problems. Due to the resolute policy of environmental protection, the technologies of innovative, fully biodegradable hydrogel composites acting as soil water sink, and fertilizer carriers with controlled release of nutrients attracted the attention of many researchers. Natural, environmentally friendly biopolymers have become an alternative to synthetic hydrogel structures. A review of recent research indicates that much simpler and cheaper solutions in the production of biodegradable superabsorbents are searched for, compared to their synthetic alternatives. Maintaining high absorption capacity, as well as adequate stability in the aqueous environment during swelling and storage is a significant characteristic. According to the sustainable development strategy, materials that are waste and do not require additional treatment can be a particularly practical solution. The research paper also draws attention to solutions for synthetic and semi-synthetic polymers that meet environmental requirements and currently have high swelling ratios compared to natural polymers, which makes them prospective in the agricultural sector.

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