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Research Article

A STUDY ON ENHANCING SOIL MOISTURE RETENTION THROUGH THE APPLICATION OF BIODEGRADABLE HYDROGELS

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ABSTRACT

Biodegradable hydrogels have emerged as a promising solution in the realm of sustainable agriculture, offering innovative approaches to address the pressing challenges faced by the industry. A simple, low-cost formulation that could be prepared without any sophisticated techniques would be helpful to the farmers in creating a biodegradable hydrogel of their own. In the current study, three distinct biopolymer-based hydrogels were prepared by the chemical polymerization technique. They are agar hydrogel, hydroxyethyl cellulose (HEC) hydrogel, and a composite hydrogel made from a 50:50 combination of agar and hydroxyethyl cellulose. The present study found that the HEC hydrogel has a maximum water absorbency of 50.76%. The loamy sand soil has a natural capacity to hold soil moisture due to the presence of 3% clay. This was further increased when the hydrogels were applied. Regardless of the hydrogel utilized, the sandy soil showed a considerable decline in water retention on the fourth day of the trial. The reduced root volume shows the effectiveness of HEC hydrogels in retaining soil moisture, thereby preventing roots from penetrating deep into the soil in search of water. Seedlings cultivated in soil containing HEC hydrogels in loamy sand and sandy soil have longer roots irrespective of the presence of hydrogel. According to a correlation analysis, there is a strong positive association between the percentage of soil moisture and the weight percentage of hydrogel degradation. Thus, the gradual deterioration of the hydrogels leads to the release of moisture into the soil.

Keywords: Biodegradable hydrogels, Hydroxyethyl cellulose, Agar, Soil moisture, Water retention.

INTRODUCTION

Water availability for irrigation has declined in the 21st century due to increased economic activity and population growth in arid and semi-arid regions. Climate change has worsened this issue, causing more frequent droughts and water shortages, particularly affecting regions like India, the Middle East, and Sub-Saharan Africa. A global survey warns that India may face severe water scarcity by 2025, highlighting the urgent need for solutions.

Agriculture has been significantly impacted by climate change, especially due to prolonged droughts and rising temperatures. Efficient water use and minimizing losses from drainage and evaporation are essential goals in soil water management (Zhou *et al*., 2020). Traditional surface irrigation methods are inefficient, as nearly half the water is lost to evaporation and runoff. While modern methods like drip and sprinkler systems reduce water waste, high costs, limited support, and equipment issues deter widespread adoption. Most of the world's 120 million farms are small-scale, and low profits make investment in advanced irrigation technologies unfeasible (Karnani, 2017).

In recent years, superabsorbent polymers (SAPs) have gained attention for agricultural use due to their ability to retain water and support plant growth under drought stress (Cheng *et al.,* 2018). Hydrogels, which have a three-dimensional polymer network that holds large amounts of water, are widely used in agriculture to improve soil quality, seed germination, and crop survival in dry regions (Bashir *et al*., 2020; Kabir *et al.,* 2018). The first water-absorbing polymer was developed in 1938, followed by

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hydrogels in the 1950s, initially used in ophthalmology. Commercial SAP production began in the 1970s, with wide applications in Japan, France, and Germany. By 1990, global production surpassed one million tons (Zohuriaan & Kabiri, 2008).

Hydrogels are classified based on their charge, sensitivity, crosslinking method, and polymer source. They can be made from natural, synthetic, or blended polymers and formed via various methods such as chemical or physical crosslinking, UV irradiation, and bulk polymerization. They are also categorized as neutral, anionic, or cationic based on the polymer's charge (Bashir *et al.*, 2020). Most commercial hydrogels use acrylic acid and acrylamide, which are expensive and potentially harmful. Many are non-biodegradable and may release toxic residues like acrylamide, a known carcinogen. Consequently, researchers are focusing on creating eco-friendly, biodegradable hydrogels from safer, plant-based materials (Slutz, 2023).

Biopolymer-based hydrogels offer several benefits: biodegradability, biocompatibility, low cost, renewability, and safety. Their decomposition can even enrich the soil with nutrients.This project involves the development of three biopolymer-based hydrogels. One uses agar powder derived from seaweed, another uses hydroxyethyl cellulose (HEC) from plant cell walls, and the third combines both. All formulations include citric acid, which helps form a water-retentive network by creating a mildly acidic environment through cationic polymerization. These hydrogels act as water reservoirs near plant roots. When mixed with soil, they can improve permeability, germination rates, and microbial activity, enhance plant growth and yield even in poor soil or drought-prone conditions. By reducing drought stress and oxidative damage, hydrogels offer a promising solution for sustainable agriculture in challenging climates (Karnani, 2017). A low-cost, easy-to-make biodegradable hydrogel could help farmers protect crops from climate change without needing advanced tools. It would also benefit urban gardeners by reducing irrigation frequency. Introducing hydrogels into agriculture supports sustainable farming. India's agricultural potential is underused, even as global food demand rises. Embracing tech-driven farming can bring environmental and economic gains. By improving soil moisture retention, hydrogels could help reclaim arid and desert lands once considered unfarmable.

MATERIALS AND METHODS

Materials and Equipment

Agar powder(60 g), Hydroxyethyl cellulose (HEC) powder (60 g),Citric acid, (30g),Weighing machine, Water, Kettle or device for boiling, 4-cup (1-liter) measuring cup,3 containers for storing each type of hydrogel, Containers or bowls that can hold at least 1 liter of water (9),Two types of potting soil (loamy sand soil and sandy soil) preferably without vermiculite or perlite (water-holding agents); enough to fill up to 60 pots, 2.00 micron mesh, Small pots, 500mL Graduated cylinder, Seeds of *Vigna angularis,* Paper towel, Ruler, Oven, Lab notebook.

Trial conditions

The experiment was conducted from April 25, 2024 to May 30, 2024 at Alphonsa College Pala (9° 42' 12" N 76° 40' 1" E) with an average temperature of 27 ° C.

Preparation of hydrogels

Three 500 mL biodegradable hydrogels were prepared. For the agar hydrogel, 40 g of agar and 10 g of citric acid were mixed in a heat-resistant cup with 500 mL of boiling water, stirred until smooth, and then poured into a labeled container to cool for at least 3 hours before testing. HEC and 50:50 agar-HEC composite hydrogels were prepared similarly.

Procedure for testing water absorption capacity of each hydrogel

Each empty container was weighed, then a large piece of hydrogel was added, and its dry weight (W_0) was recorded along with the total weight. Water was added to fully submerge the hydrogels. After one hour, the saturated samples were removed, surface water was filtered off, and the swollen weight (W_1) was measured. The water absorption capacity *(W.A.C,* $g{\cdot}g^{-1}$*)* was calculated using the equation:

Water Absorption Capacity, W.A.C($g.g^{-1}$) $= (W_1 - W_o) / W_o$

Where,

W_o denotes the dry weight of the hydrogel

W_1 is the weight of swollen hydrogel samples

The water absorption capacities of reported results were averages of 3 measured values. (Vo *et al.,* 2022).

Determining soil texture

Soil samples were collected from two sites in Idukki district: sandy soil from the Thodupuzhayar River bank (9°47'20.0"N, 76°50'51.9"E) and loamy sand from a field in Purapuzha panchayat (9°50'56.6"N, 76°37'51.8"E), avoiding areas likely to contain vermiculite or perlite. Both samples were sieved through a 2.00-micron mesh to remove debris. Soil texture was analyzed microscopically by measuring the Feret diameter of 100 particles. Texture classification followed the World Reference Base for Soil Resources (4th ed., 2022). The soils were identified as loamy sand (82% sand, 15% silt, 3% clay) and sandy soil (99% sand, 1% silt).

Effects of hydrogel on the moisture retention in soil with and without hydrogels

This test aimed to assess how hydrogel amendment affects moisture retention in sandy and loamy sand soils. Soil samples were dried at 45°C until reaching a constant weight. A mixture of 25 g dried hydrogel and 75 g dried soil was placed in plastic pots, with untreated soil serving as the control. Each pot was weighed, then 50 mL of distilled water was added and the weight was recorded again. Daily weight measurements were taken until no further weight loss was detected.

Water Retention was evaluated using the formula:

Water Retention, WR (%) =(Wt-W)/ Wi-W ×100

Where,

W is the weight of the sample without water,

Wi is the weight of the sample after adding the water and

Wt refers to the weight of the sample after specified time intervals.

Water content in the soil, monitored at 26˚C for 20 days following the first irrigation, was recorded. The experiment was conducted on both loamy sand and sandy soil with three trials to obtain accurate and repeatable data.

Calculating the average root volume by displacement method

Each pot contained 120 g of either sandy or loamy sand soil mixed with 40 g of hydrogel (3:1 ratio). Control pots had soil only. Four *Vigna angularis* seeds were sown 1 cm below the surface, and 50 ml of water was added. After 14 days of growth, roots were separated, washed, and placed in 50 ml of water in a 100ml cylinder. The volume displaced was measured in cm^3 per pot (1 cm^3 = 1 ml).

Determining the root length at day 14 in Loamy sand and Sandy soil with and without hydrogel

For each trial, 120 g of soil was mixed with the respective hydrogel and placed in a pot, with four *Vigna angularis* seeds sown 1 cm below the surface. After adding 50 mL of water to saturate the soil, the plants were cultivated for 14 days. On day 14, seedlings were gently washed with tap water, dried with paper towels, and root lengths were measured. Each treatment was replicated three times using both sandy and loamy sand soils to ensure accuracy.

Biodegradation of hydrogels using soil burial method

Soil burial is a standardized method used to assess hydrogel degradation by burying the material in soil and evaluating weight loss over time. The result is expressed as a degradation percentage for a predetermined time of 12 days. In this experiment, plastic pots were filled to 80% capacity with soil, and 10 g of hydrogel was buried 5 cm below the surface. On the first day, 20 ml of water was added. Hydrogels were retrieved on days 4, 8, and 12, washed with distilled water, dried in an oven to constant weight, and reburied after weighing. On days 4 and 8, 10 ml of water was added.

Degradation (%) = (W_o -Wt)/ W_o × 100

Where,

Wo is the initial weight of the before degradation

Wt are the weights of the hydrogel at specific time intervals after the beginning of degradation

Statistical analysis

Data Analysis One-way analysis of variance (ANOVA), t-Test: Paired Two Sample for Means and correlation analysis were conducted using Microsoft Excel software (15.0.4420.1017). The statistical difference was considered significant if $p < 0.05$.

RESULTS AND DISCUSSION

The current study created three different types of biodegradable hydrogels. To ensure repeatable and accurate results, all experiments were subjected to three trials under the same environmental conditions. The experiments took place at 28˚C room temperature for 30 days, beginning April 25, 2024 and ending May 30, 2024. The study area is situated at 9° 5056.6 N and 76° 3751.8 E. Water absorption capacity is a significant measure that determines the effectiveness of the hydrogel in taking up the available excess amount of water. Thus, it is significant in evaluating a hydrogel for its potential application in agriculture**.**

Table 1. Relative percentage of water absorbed by each hydrogel.

Type of hydrogel	Relative% water absorbed
Agar	12.39%
Hydroxyethyl cellulose (hec)	50.76%
Composite hydrogel (agar + hec)	36.85%

Results obtained on the average relative percentage of water absorbed for each type of hydrogel are plotted on a pie chart.

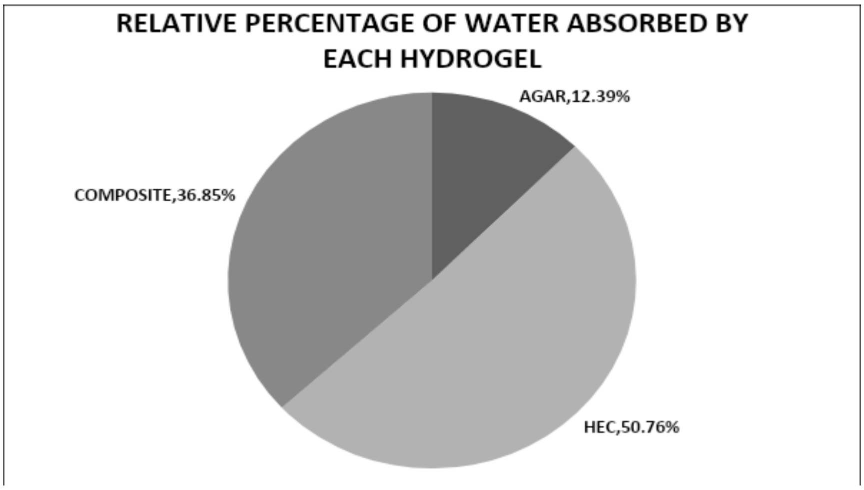

Figure 1. Graphical representation of relative percentage of water absorbed by each hydrogel

Hydrogel derived from the chemical polymerization of Hydroxyethyl cellulose (HEC) offers the maximum water absorbency (50.76%). As Hydroxyethyl cellulose contains numerous hydroxyl groups, it increases the hydrophilic nature of the hydrogel, resulting in a faster rate of water absorption. Thus the HEC hydrogel is found to be more effective in absorbing water which would be helpful to increase the soil moisture after a short rainfall or irrigation at the times of drought. Capacity for water retention in soil is important for understanding the potential of hydrogel as a soil conditioner. The water content in the soil, monitored over several days following the first irrigation, was significantly affected by the presence of the hydrogel. Loamy soil is a mixture of clay, sand, and silt, which consists of additional organic matter and is very fertile compared to other types of soil. It is well suited for cultivation as the plant roots get sufficient amounts of water and nutrients for their growth and development. This experiment attempts to evaluate whether the application of hydrogel can further increase soil moisture.

Table 2. Percentage of water retention in loamy sand soil amended with and without hydrogels.

Days	Type of hydrogel			
	Agar	Composite	HEC	Control
Day 0	100.00	100.00	100.00	100.00
Day 4	70.63	77.11	80.00	71.74
Day 8	48.45	58.67	63.95	50.00
Day 12	25.29	36.23	47.09	31.09
Day 16	22.29	31.73	41.29	26.19
Day 20	2.59	6.33	9.09	3.19

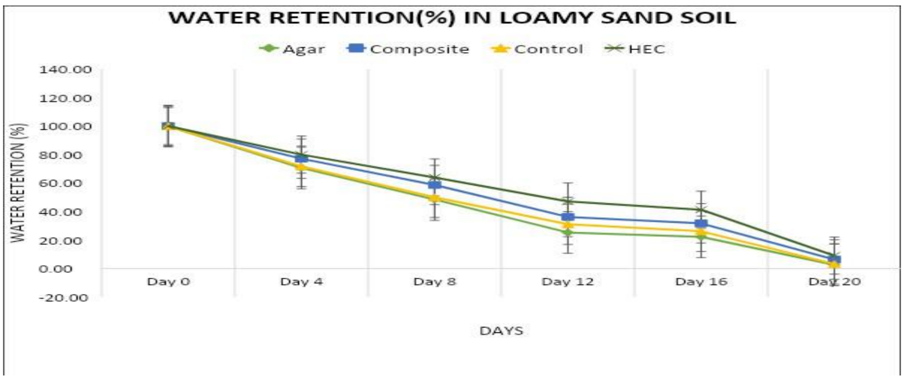

Figure 2. Water retention capacity (%) of pure loamy sand soil (Control) and soil containing the hydrogels Agar, Composite and HEC.

The graph in Figure 3.2 shows a continuous decrease in water retention capacity in soil and loss of water over the course of 20 days. The soil samples containing hydrogel possessed substantially more humidity, which confirms their capacity for water uptake. The soil containing HEC hydrogel had a greater amount of water retention than pure soil, which served as the control. As the soil's humidity reduced, it gradually released the water it had absorbed by diffusion. Consequently, agricultural land with soil containing the hydrogel could possess more moisture during periods of subsequent dryness since water absorbed during irrigation and rain would be gradually released from the added hydrogels.

Table 3. ANOVA Single factor analysis for water retention in loamy sand soil amended with hydrogels at level of significance, ∝=0.05%.

ANOVA Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	23026.72	5	4605.344	116.9118	4.49E-13	2.772853
Within Groups	709.0488	18	39.3916			
Total	23735.77	23				

The calculated value of F (116.91) is numerically greater than the table value of F (2.77). Thus, the null hypothesis is rejected and the alternative hypothesis is accepted i.e., the three hydrogels differ significantly in their water retention capacity in loamy sand soil. Sandy soils are those that are generally coarse-textured until 50 cm deep and consequently retain few nutrients and have a low water-holding capacity. Thus, they are known as the poorest type of soil for agriculture and growing plants. As a result, modifying such soil is critical for making areas with sandy soil agriculturally viable.

Table 3. Percentage of water retention in sandy soil amended with and without hydrogels.

	TYPE OF HYDROGEL			
Day	**Agar**	**Composite**	**HEC**	**Control**
Day 0	100.00	100.00	100.00	100.00
Day 4	60.87	64.34	67.03	59.32
Day 8	40.24	43.66	45.05	37.77
Day 12	26.45	32.23	38.55	20.69
Day 16	8.67	11.24	14.78	4.78
Day 20	2.59	6.74	9.98	0.84

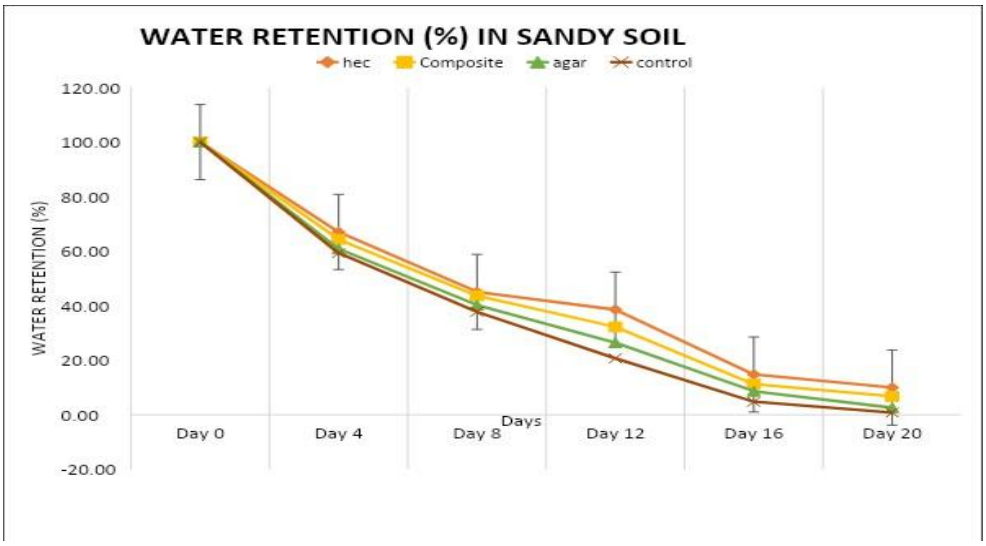

Figure 3. Water retention capacity (%) of pure sandy soil (Control) and soil containing the hydrogels Agar, Composite and HEC.

The graph in Figure 3.3 shows a continuous decrease in water retention capacity in soil and loss of water over the course of 20 days. The soil containing HEC hydrogel had a greater amount of water retention than pure soil, which served as the control. As the soil's humidity reduced, it gradually released the water it had absorbed by diffusion. The composite hydrogel is also possessing water retention capacity closer to the HEC hydrogel. The average difference between the water retention capacity of composite and HEC hydrogels is 3.40%. At the end day of the experiment HEC hydrogels possess a retention capacity of 9.98%.

Table 4. ANOVA Single factor analysis for water retention in sandy amended with hydrogels at level of significance, ∝=0.05%.

ANOVA Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	25417.33	5	5083.465	261.7814	3.77E-16	2.772853
Within Groups	349.5373	18	19.41874			
Total	25766.86	23				

Calculated value of F (261.78) is numerically greater than the table value of F (2.77). Thus, the null hypothesis is rejected and the alternative hypothesis is accepted i.e., the three hydrogels differ significantly in their water retention capacity in sandy soil.A short-term growth assessment was conducted with the legume plant *Vigna angularis* in two types of soil: loamy sand soil and sandy soil treated with biodegradable hydrogels. The root length and root volume were computed to evaluate how the hydrogels aided in the growth of plants during water stress conditions. The root volume, a component of root morphology, differs significantly depending on the plant species, soil composition, and water and mineral nutrient availability. Thus, root volume can be used as a parameter for assessing the drought stress conditions faced by the plants Seedlings cultivated in non-amended soils had a greater root volume than those grown in hydrogel-amended soils. Plants growing in soil that has been treated with HEC hydrogels have lesser root volume. Thus, it indicates the efficiency of HEC hydrogels in retaining soil moisture so that the roots do not have to penetrate deep into the soil in search of water. As the plant is subjected to water stress conditions, it develops a good root length to uptake more water from the soil. So evaluating the root length is significant in analysing the growth of plants in a drought condition.

Table 5. Average root volume in cm3.

Type of hydrogel	Average Root volume (in cm3) in loamy sand soil	Average Root volume (in cm3) in sandy soil
AGAR	0.5	0.56
COMPOSITE	0.39	0.44
HEC	0.43	0.36
CONTROL	0.78	0.58

Table 6. Root growth at day 14 in Loamy sand and Sandy soil with and without hydrogel.

Type of hydrogel	Loamy sand soil		Sandy soil	
	Soil amended with hydrogel	Control	Soil amended with hydrogel	Control
Agar	7.68	8.83	10.62	10.64
HEC	12.07	8.83	13.59	10.64
Composite	7.86	8.83	13.26	10.64

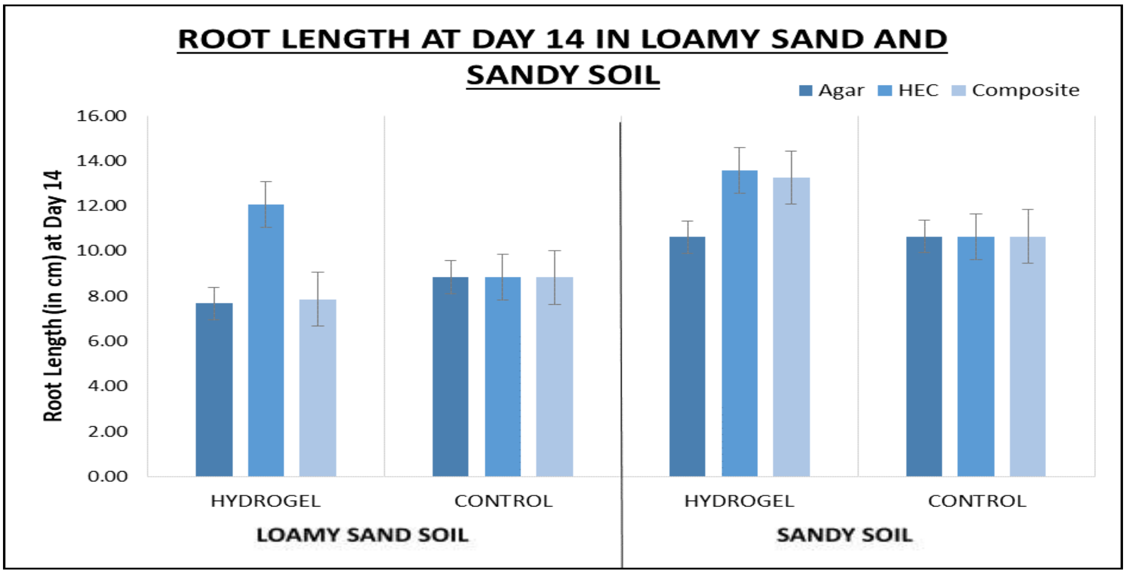

Figure 4. Graphical representation of root growth at day 14 in Loamy sand and Sandy soil with and without hydrogel.

*All data are means of three replications. Statistical analysis for comparison between control and hydrogel conditions: unpaired Student's t-test. ($p < 0.05$).

The soil modified with HEC hydrogels had longer roots than plants cultivated in pure soil. The composite hydrogel also showed a similar trend in the terms of root length. Thus, even when hydrogel with a capacity to hold soil moisture is applied, the plants can have longer roots. According to the weight loss of each hydrogel by the soil burial method, the percentage of degradation that took place within the short term of 12 days was computed.

Table 7. Percentage degradation of hydrogels using soil burial method.

Type of hydrogel	Weight loss (%) at different time intervals		
	day 4	day 8	day 12
Agar	58.14	34.88	27.91
HEC	60.78	29.41	23.53
Composite	69.39	38.78	24.49

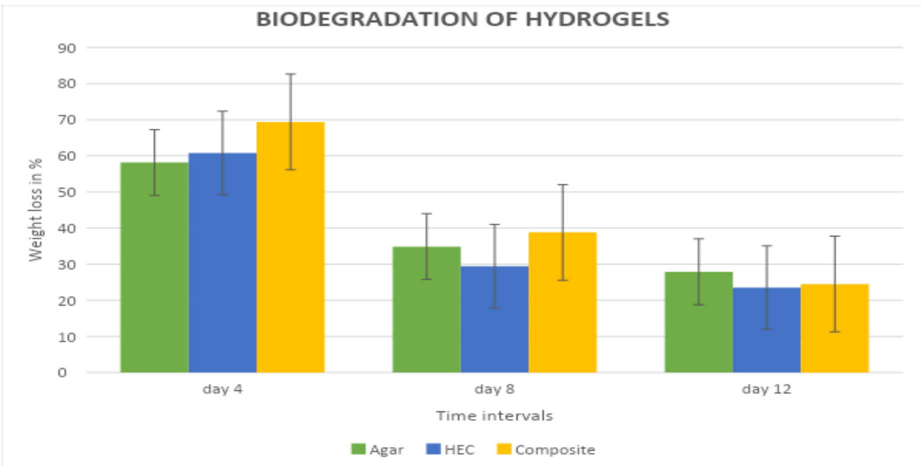

Figure 5. Graphical representation of the biodegradation of hydrogels with weight loss in percentage against different time intervals

Table 8. ANOVA Single factor analysis for percentage degradation of hydrogels with level of significance, ∝=0.05%.

ANOVA						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	2292.587	2	1146.294	55.45581	0.00013517	5.143253
Within Groups	124.0224	6	20.6704			
Total	2416.61	8				

The calculated value of F (55.45) is numerically greater than the table value of F (5.14). Thus, the null hypothesis is rejected and the alternative hypothesis is accepted i.e., the three hydrogels differ significantly in their mean percentage of degradation.

Table 9. Percentage of moisture retention in soil and biodegradation of hydrogel.

	AGAR HYDROGEL		**HEC HYDROGEL**		**COMPOSITE HYDROGEL**	
	% of Biodegradation	% of moisture retention in soil	% of Biodegradation	% of moisture retention in soil	% of Biodegradation	% of moisture retention in soil
Day 4	58.14	70.63	69.39	77.11	69.39	77.11
Day 8	34.88	48.45	38.78	58.67	38.78	58.67
Day 12	27.91	25.29	24.49	36.23	24.49	36.23
r*	0.95		0.92		0.96	

*r= correlation coefficient

The correlation coefficient of all the three hydrogels is above 0.9 which indicates the percentage of moisture retention and biodegradation are positively correlated. Thus, an increase in biodegradation leads to the release of moisture into the soil. The agar hydrogels having firm consistency on desiccation show a lower rate of degradation. Thus, they can resist the instant microbial attack. As a result, the use of agar-based hydrogels will be appropriate for the gradual and long-term release of water and nutrients. The HEC hydrogels were the first to show degradation. The deterioration of HEC hydrogels started on the second day. Thus, the HEC can be used to treat short-term water stress scenarios. So, hydrogels manufactured from Hydroxyethyl cellulose pose substantially less of a harm to the environment over time. The composite hydrogels exhibit characteristics intermediate between HEC and agar hydrogels. Thus, composite hydrogels hold potential for the creation of a modified hydrogel that meets the requirements of water and environmental durability. Hydrogels synthesized from hydroxyethyl cellulose (HEC) through chemical polymerization showed the highest water absorbency at 50.76%. Among the three tested types, water absorption followed the order: agar (12.39%), composite (36.85%), and HEC outperforming the others by a margin of 38.37% over agar. The high hydrophilicity of HEC, due to its abundant hydroxyl groups, enables faster and more efficient water uptake, making it potentially beneficial for improving soil moisture after short rainfall events.

In comparison, synthetic hydrogels have significantly higher absorption capacities. Vundavalli *et al*. (2015) reported silver-coated super-absorbent polymers absorbing up to 190 g/g in distilled water, 161 g/g for tap water, and 119 g/g for saline water. While Akhtar *et al*. (2004) found values as high as 505 g/g using hydrogels based on acrylic acid salts. These findings highlight that synthetic hydrogels outperform biodegradable, natural polymer-based hydrogels in water absorption efficiency. Soils treated with hydrogels retained significantly more moisture, confirming their water absorption capacity. HEC hydrogel showed the highest retention in both loamy sand and sandy soils, followed by the composite and agar hydrogels. During the 20-day experiment, hydrogels gradually released stored water as soil moisture declined. On day 4, loamy sand control soil retained 71.74% moisture, while HEC, agar, and composite hydrogels retained 80%, 77.11%, and 70.63%, respectively. In sandy soil, due to higher permeability, retention dropped to 67.03% (HEC), 64.34% (composite), and 60.87% (agar).

By day 20, loamy sand treated with HEC retained 9.09% moisture (control: 3.19%), and sandy soil retained 9.98% (control: 0.84%). Composite and agar hydrogels also improved water retention, though to a lesser extent. These findings suggest that hydrogels can help maintain soil moisture during dry periods by slowly releasing absorbed water. Cheng *et al*. (2018) discovered that adding super-absorbents to sandy loam, loam, and paddy soil considerably improved the soil's water holding capacity and retention qualities. After 8 days, the relative water content of sandy soil, loam soil, and paddy soil treated with super absorbent was 42%, 56%, and 45%, respectively. However, the relative water content of soils (sandy loam, loam, and paddy soil) without hydrogels was only 2%, 18%, and 4%. Previous research found that adding typical hydrophilic polymers to sandy soil increased its water retention capacity to levels equal to silty clay or loam soils (Johnson, 1984; Hutterman *et al*., 1999). Shahid *et al*. (2012) observed that adding 0.1 to 0.4% (w/w) of a poly-acrylamide-based superabsorbent hydrogel enhanced the water retention of a sandy loam soil by 60 to 100% at field capacity, with the water retention rising with the quantity of the hydrogel. Similar results were obtained on a sandy soil treated with hydrogel, although the hydrogel influence decreased as soil salinity spiked, confirming a common problem with hydrogels (Dorraji *et al*., 2010).

Seedlings grown in untreated soils had larger root volumes (0.78 cm^3 in loamy sand and 0.58 cm^3 in sandy soil) compared to those in hydrogel-treated soils. In loamy sand, root volumes with agar, composite, and HEC hydrogels were 0.5 cm^3, 0.39 cm^3, and 0.43 cm^3, respectively. In sandy soil, the values were 0.56 cm^3 (agar), 0.44 cm^3 (composite), and 0.36 cm^3 (HEC). The reduced root volumes in HEC-treated soil indicate improved moisture availability near the surface, reducing the need for deeper root growth. Despite smaller root volumes, seedlings in HEC-amended soils had longer roots—12.07 cm (loamy sand) and 13.59 cm (sandy soil)—suggesting that water-retentive hydrogels like HEC support root elongation. Composite hydrogels showed a similar trend, indicating that moisture-retentive soils still support root growth.Cheng *et al*. (2018) found that super-absorbents play a crucial role in maize seed development. Measurements of seeding lengths demonstrated that hydrogels treatment at concentrations lower than 0.2% improved root growth. Maize seeds treated with hydrogels produced significantly longer average seedling lengths than the control groups, which included sandy loam, loam, and paddy soils. The 0.2% treatments had the longest seedling height of all the groups, about double that of the 0% and 0.5% treatments combined. Montesano *et al*. (2015) found that the cucumber culture experiment results demonstrated an overall increase in plant growth when treated to hydrogel treatment at the time of analysis. The hydrogel increased the plants' height (180 vs. 158 cm), total fresh biomass (1753 vs. 913 g), leaf, stem, and fruit fresh biomass (468 vs. 285 g, 427 vs. 264, and 858 vs. 364, respectively), and leaf area. The findings support the widely documented favorable benefits of hydrogels on plant development and the decrease of the negative effects of water stress (Akhter *et al*., 2004; Shahid *et al*., 2012).

The percentage of weight loss on the fourth day of soil burial was 58.14% for agar, 60.78% for HEC, and 69.39% for composite hydrogels. The agar hydrogels decomposed slower than the other hydrogels. This could account for the hydrogel's hard consistency. The moisture provided by the hydrogels on day 4 is 70.63% for agar, 80% HEC, and 77.11% composite hydrogels. The correlation analysis of the percentage of soil moisture and degradation of hydrogels in weight percentage showed that there exists a highly positive correlation between them. Thus, the gradual degradation of the hydrogels leads to the release of moisture into the soil. Melendres *et al*. (2022) reported a reduction in absorption capacity and permeability after subjecting samples to biodegradability tests in a high-humidity environment at around 33˚C. Rop *et al*. (2019) noted slow mass loss in cellulose-grafted polymer hydrogel during the first four weeks, followed by a quicker loss from the fourth to the twelfth week. Polymer hydrogels lacking cellulose showed no significant mass change. After 14 weeks, the mass loss was around 25% for cellulose-grafted polymer hydrogel and 5% for polymer hydrogel without cellulose.

CONCLUSION

The current study describes a set of hydrogels that can be created without much sophisticated technique in a cost-effective manner. The uniqueness of these hydrogels is their immediate preparation and use by the farmers themselves. The components used for the preparation are both eco-friendly and non-toxic. The water absorption capacity, the percentage of water retention in loamy sand soil and sandy soil, the growth of seeds in hydrogel-added soil, and the biodegradability of the hydrogels were evaluated. Hydroxyethyl cellulose (HEC) hydrogels are the most promising form of biodegradable hydrogel that has the potential for maximum water absorbency and water retention. As they could provide enough moisture to the soil, they helped the plants surpass the water stress condition for a good period of time. Even the growth of the seedlings during a water shortage is not affected much if the soil is altered with a suitable amount of hydrogel. Thus, the tested hydrogel proved to be suitable for potential use in agriculture, with a particular potential benefit for short-growing cycle crops. The other two formulations of hydrogels, composite hydrogel and agar hydrogel, have the ability to retain moisture, even though at a lower rate. Thus, they can be further modified with the combination of other natural polymers with similar properties to create more diverse types of biodegradable hydrogels.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

The authors are confirming that all ethical issues have been dealt with the research ethics guidelines provided by the PG and Research Department of Zoology, Alphonsa College Pala, Kottayam, Kerala.

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

REFERENCES

Akhter, J., Mahmood, K., Malik, K., Mardan, A., Ahmad, M., & Iqbal, M. (2004). Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. *Plant, Soil and Environment, 50*(10), 463-469. https://doi.org/10.17221/4059-pse

Alam, M. N., & Christopher, L. P. (2018). Natural cellulose-chitosan cross linked superabsorbent hydrogels with superior swelling properties. *ACS Sustainable Chemistry & Engineering, 6*(7), 8736-8742. https://doi.org/10.1021/acssuschemeng.8b01062

Bashir, S., Hina, M., Iqbal, J., Rajpar, A. H., Mujtaba, M. A., Alghamdi, N. A., Wageh, S., Ramesh, K., & Ramesh, S. (2020). Fundamental concepts of hydrogels: Synthesis, properties, and their applications. *Polymers, 12*(11), 2702. https://doi.org/10.3390/polym12112702

Cheng, D., Liu, Y., Yang, G., & Zhang, A. (2018). 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. *Journal of Agricultural and Food Chemistry, 66*(23), 5762–5769. https://doi.org/10.1021/acs.jafc.8b00872

Cuadri, A., Bengoechea, C., Romero, A., & Guerrero, A. (2016). A natural-based polymeric hydrogel based on functionalized soy protein. *European Polymer Journal, 85,* 164–174. https://doi.org/10.1016/j.eurpolymj.2016.10.026

Demitri, C., Scalera, F., Madaghiele, M., Sannino, A., & Maffezzoli, A. (2013). Potential of cellulose-based superabsorbent hydrogels as water reservoir in agriculture. *International Journal of Polymer Science, 2013,* 1-6. https://doi.org/10.1155/2013/435073

Heise, K., Kirsten, M., Schneider, Y., Jaros, D., Keller, H., Rohm, H., Kalbitz, K., & Fischer, S. (2019). From agricultural byproducts to value-added materials: Wheat straw-based hydrogels as soil conditioners? *ACS Sustainable Chemistry & Engineering, 7*(9), 8604–8612. https://doi.org/10.1021/acssuschemeng.9b00378

Hüttermann, A., Zommorodi, M., & Reise, K. (1999). Addition of hydrogels to soil for prolonging the survival of *Pinus halepensis* seedlings subjected to drought. *Soil & Tillage Research, 50*(3–4), 295–304. https://doi.org/10.1016/s0167-1987(99)00023-9

Johnson, M. S. (1984). The effects of gel-forming polyacrylamides on moisture storage in sandy soils. *Journal of the Science of Food and Agriculture, 35*(11), 1196–1200. https://doi.org/10.1002/jsfa.27403511

Kabir, S. M. F., Sikdar, P. P., Haque, B., Bhuiyan, M. A. R., Ali, A., & Islam, M. N. (2018). Cellulose-based hydrogel materials: Chemistry, properties and their prospective applications. *Progress in Biomaterials, 7*(3), 153–174. https://doi.org/10.1007/s40204-018-0095-0

Karnani, S. (2017). Hydrogel agriculture technology. Retrieved from https://vikaspedia.in/agriculture/best-practices/sustainable-agriculture/crop-management/hydrogel-agriculture-technology

Melendres, A. V., Manacob, C. J. A., & Vera Cruz, R. P. (2022). Effect of corn starch on the biodegradability and absorbency of superabsorbent polymer. *Chemical Engineering Transactions, 92,* 427–432. https://doi.org/10.3303/CET2292072

Mishra, S., Thombare, N., Ali, M., & Swami, S. (2018). Applications of biopolymeric gels in agricultural sector. In *Polymer gels* (pp. 185–228). Singapore: Springer. https://doi.org/10.1007/978-981-10-6080-9_8

Montesano, F. F., Parente, A., Santamaria, P., Sannino, A., & Serio, F. (2015). Biodegradable superabsorbent hydrogel increases water retention properties of growing media and plant growth. *Agriculture and Agricultural Science Procedia, 4,* 451–458. https://doi.org/10.1016/j.aaspro.2015.03.052

Oladosu, Y., Rafii, M. Y., Arolu, F., Chukwu, S. C., Salisu, M. A., Fagbohun, I. K., Muftaudeen, T. K., Swaray, S., & Haliru, B. S. (2022). Superabsorbent polymer hydrogels for sustainable agriculture: A review. *Horticulturae, 8*(7), 605. https://doi.org/10.3390/horticulturae8070605

Rop, K., Mbui, D., Njomo, N., Karuku, G. N., Michira, I., & Ajayi, R. F. (2019). Biodegradable water hyacinth cellulose-graft-poly (ammonium acrylate-co-acrylic acid) polymer hydrogel for potential agricultural application. *Heliyon, 5*(3), e01416. https://doi.org/10.1016/j.heliyon.2019.e01416

Shahid, S. A., Qidwai, A. A., Anwar, F., Ullah, I., & Rashid, U. (2012). Improvement in the water retention characteristics of sandy loam soil using a newly synthesized poly (acrylamide-co-acrylic acid)/AlZnFe2O4 superabsorbent hydrogel nanocomposite material. *Molecules, 17*(8), 9397–9412. https://doi.org/10.3390/molecules17089397

Slutz, S. (2023). Can biodegradable hydrogels help conserve water in farming? Retrieved from https://www.sciencebuddies.org/science-fair-projects/project_ideas/AgTech_p013/agricultural-technology/water-conservation-hydrogels

Sulianto, A. A., Adiyaksa, I. P., Wibisono, Y., Khan, E., Ivanov, A., Drannikov, A., Ozaltin, K., & Di Martino, A. (2023). From fruit waste to hydrogels for agricultural applications. *Clean Technologies, 6*(1), 1. https://doi.org/10.3390/cleantechnol6010001

Vo, T. S., Vo, T. T. B. C., Tran, T. T., & Pham, N. D. (2022). Enhancement of water absorption capacity and compressibility of hydrogel sponges prepared from gelatin/chitosan matrix with different polyols. *Progress in Natural Science, 32*(1), 54-62. https://doi.org/10.1016/j.pnsc.2021.10.001

Vundavalli, R., Vundavalli, S., Nakka, M., & Rao, D. S. (2015). Biodegradable nano-hydrogels in agricultural farming – Alternative source for water resources. *Procedia Materials Science, 10,* 548-554. https://doi.org/10.1016/j.mspro.2015.06.005

Xiong, B., Loss, R. D., Shields, D., Pawlik, T., Hochreiter, R., Zydney, A. L., & Kumar, M. (2018). Polyacrylamide degradation and its implications in environmental systems. *npj Clean Water, 1*(17), 1-9. https://doi.org/10.1038/s41545-018-0016-8

Zhou, X., Zhang, P., Zhao, F., & Yu, G. (2020). Super moisture absorbent gels for sustainable agriculture via atmospheric water irrigation. *ACS Materials Letters, 2*(11), 1419-1422. https://doi.org/10.1021/acsmaterialslett.0c00439

Zohuriaan, J., & Kabiri, K. (2008). Superabsorbent polymer materials: A review. *Iranian Polymer Journal, 17*(6), 451-477.