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Determining the Water Absorption and Retention of Biodegradable Hydrogels of Differing Compositions

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ABSTRACT

This research addresses the need for sustainable water management in agriculture by testing biodegradable hydrogels made from natural materials: agar and methyl cellulose (MEC). Focused on eco-friendly alternatives to synthetic counterparts, this project aims to contribute to sustainable agricultural practices, addressing water scarcity and environmental pollution. Three hydrogels—agar, MEC, and a combination of both—were evaluated for water absorption, air-water loss, and soil-water retention. Insights into their performance under two conditions were gained through experimentation, contributing valuable information to sustainable water management in agriculture. When the hydrogels were soaked in water and tested for water absorption in an air environment, the MEC hydrogel demonstrated the best performance with an average relative water absorption of approximately 66.9%. In soil-water conservation tests, the agar hydrogel exhibited the least water loss, with an average relative change in water of approximately -48.1%, outperforming the other hydrogels. Despite its initial poor performance in an air environment, likely due to its liquid state, the agar hydrogel's effectiveness in true irrigation conditions is anticipated based on its performance in the soil environment. The quick gel formation of agar is not critical in real agricultural environments. While MEC is more common in commercial use due to its strong gel-forming ability, agar's potential can be enhanced with different formulations that promote gel formation, thereby improving water retention in agricultural settings. This project provides valuable insights into the application of biodegradable hydrogels for sustainable water management in agriculture, highlighting the potential of natural materials to address critical environmental challenges.

Introduction

The research question tested in this experiment is: Can the utilization of biodegradable hydrogels in agricultural practices serve as an effective and environmentally sustainable solution for enhancing water retention in soil, thus mitigating water scarcity challenges and optimizing crop growth while ensuring minimal environmental impact?

Many towns, and even whole countries, are at an all-time low in terms of water resources due to many causes including poor water management, climate change, and political disagreements. For example, the Ogallala Aquifer crosses eight state lines in the United States of America and numerous farmers rely on this water resource to irrigate their crops. However, this aquifer is being relied on too heavily, as the water being taken from it is not being naturally replenished at the rate it needs to be. Farmers, specifically in Kansas, United States of America, are suffering due to droughts and a lack of water needed for their agriculture. This is just one of many cases of lack of water affecting a population. Many cannot afford to build new wells or to outsource water and we believe that it is important to create a sustainable solution that prevents water resource depletion while allowing for the growth of crops.

Hydrogels are networks of macromolecules with the ability to absorb and release water in response to specific environmental stimuli. Both agar and MEC are inherently affordable ingredients that can be used for water absorption and retention. There are other existing solutions for enhancing water retention in soil, but the most widely used ones, vermiculite and perlite, cause environmental issues. They not only cause habitat loss due to them being mined, often unethically and irresponsibly, but they also contribute to soil erosion. The vast majority of soil additives used for water retention cause problems like these. Therefore, focused on eco-friendly alternatives to synthetic counterparts, our project aims to contribute to sustainable agricultural practices, addressing water scarcity and environmental pollution.

Background Research

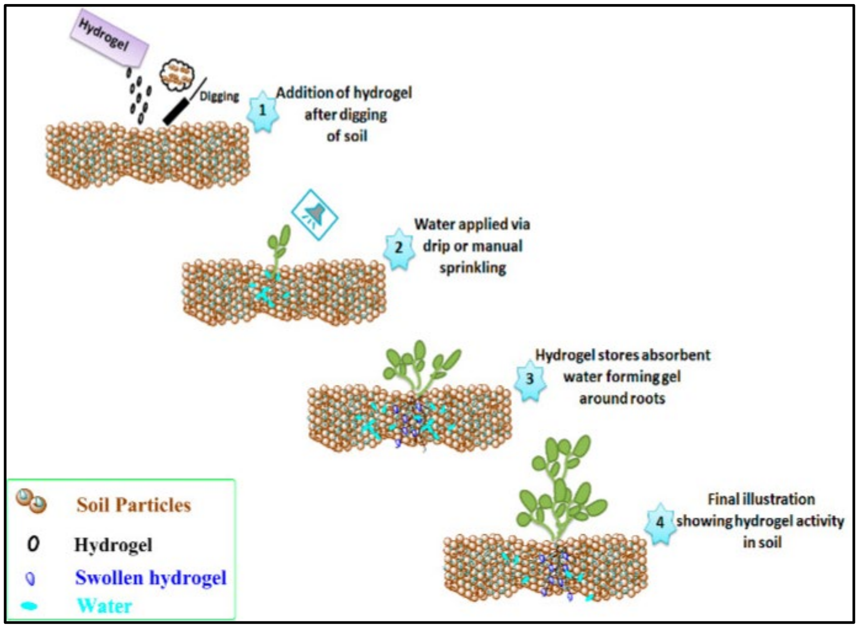

Figure 1. Steps of hydrogel incorporation in an agricultural field for plant water absorption. Figure from source 3).

Agar

Agar, derived from seaweed, is a polysaccharide with a long history of use in various applications, including culinary and scientific fields. In our context, agar's role as a hydrogel is notable. Agar has a high water-absorbing capacity. When agar comes into contact with water, it forms a gel due to the intricate network it creates. One of the fascinating aspects of agar is its stability in the gel state. Unlike some hydrogels that may undergo phase changes or degrade rapidly, agar hydrogels tend to maintain their structure, providing a stable environment for water retention. This property is of particular interest as we explore the longevity of hydrogel performance, especially in the context of conserving water in soil over an extended period. Microorganisms, such as bacteria and fungi, can break down agar into simpler compounds through enzymatic actions. The primary breakdown products of agar are typically sugars, which can be further metabolized by microorganisms.

Agar hydrogels have a unique property where they remain stable across a wide range of temperature conditions, maintaining their structural integrity and functionality. This resilience is primarily due to the unique chemical structure of agar, specifically long polysaccharide chains. These chains form a network when dissolved in water and subsequently cooled, creating a gel matrix with strong intermolecular forces. Unlike many other hydrogels that may soften or liquefy at higher temperatures, agar hydrogels remain stable up to approximately 85°C. This thermal stability is due to the hydrogen bonds and the semi-crystalline structure of agar, which resist thermal agitation.

Moreover, at lower temperatures, agar does not undergo significant phase transitions that would compromise its function. This allows agar hydrogels to function in diverse climatic conditions and agricultural practices globally. They can effectively absorb and release water in response to soil and environmental moisture changes without degrading. Overall, agar's property provides a reliable means to mitigate water scarcity in soils subjected to fluctuating temperatures and supports crop growth across different geographic regions.

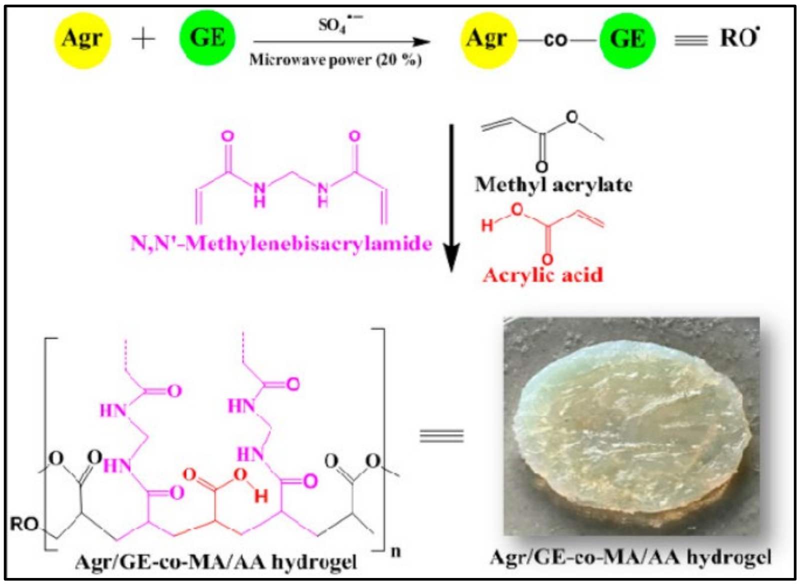

Figure 2. Representation of the synthesis of agar hydrogel. Figure from source 3). After the agar is provided with heat and a crosslinking agent, in our experiment boiling water and citric acid, it crosslinks and forms a hydrogel.

Methyl Cellulose

MEC, a derivative of cellulose found in the cell walls of plants, exhibits a unique ability to form gels in aqueous solutions. It is a hydrophilic polymer, meaning it has a strong affinity for water. When MEC encounters water, it undergoes a transformation, swelling and forming a gel-like structure. This property is crucial in our investigation as we seek to understand how MEC hydrogels interact with water during absorption experiments. Furthermore, MEC's gelation is reversible. As the hydrogel absorbs water, it not only retains moisture but also has the potential to release it under certain conditions. This reversibility is a key factor when considering the long-term implications of MEC hydrogels in soil and their role in water conservation. When MEC is released into the environment, microorganisms such as bacteria and fungi can enzymatically break down its chemical structure. The biodegradation process involves the breakdown of the polymer into simpler compounds, ultimately leading to the formation of water and other natural byproducts.

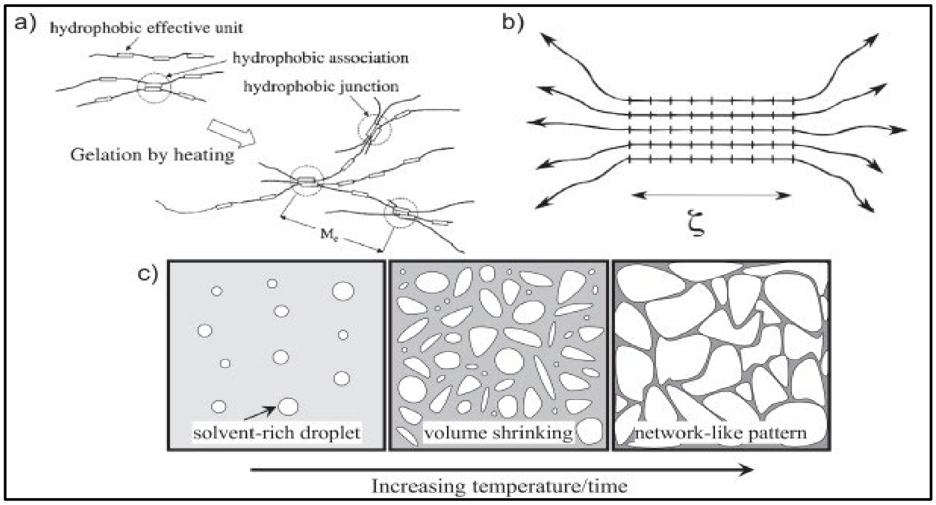

Figure 3. Methyl cellulose solutions and gelation process. Figure from source 4).

Vermiculite and Perlite

The exclusion of vermiculite and perlite is crucial for maintaining the purity of our experimental conditions. These additives, designed to enhance water retention, could potentially skew our research by influencing the water-absorbing capabilities of the biodegradable hydrogels. By using soil without these additives, we ensure a clearer understanding of how the hydrogels directly interact with the natural soil environment.

Citric Acid

Citric acid serves as a crosslinking agent in the synthesis of hydrogels through a process known as crosslinking or gelation. In hydrogel preparation, polymers are typically dissolved in a solvent, and crosslinking agents are added to facilitate the formation of a structure. The crosslinks create a stable gel structure, giving the hydrogel its unique properties. Citric acid contains multiple functional groups, such as carboxylic acid groups, which can participate in the crosslinking process. When citric acid reacts with other components in the hydrogel formulation, it forms bridges between polymer chains, enhancing the overall stability and properties of the hydrogel. Citric acid, being a natural compound, can undergo biodegradation. In the environment, microorganisms can metabolize citric acid, breaking it down into organic compounds. This natural degradation process helps minimize the environmental impact of citric acid.

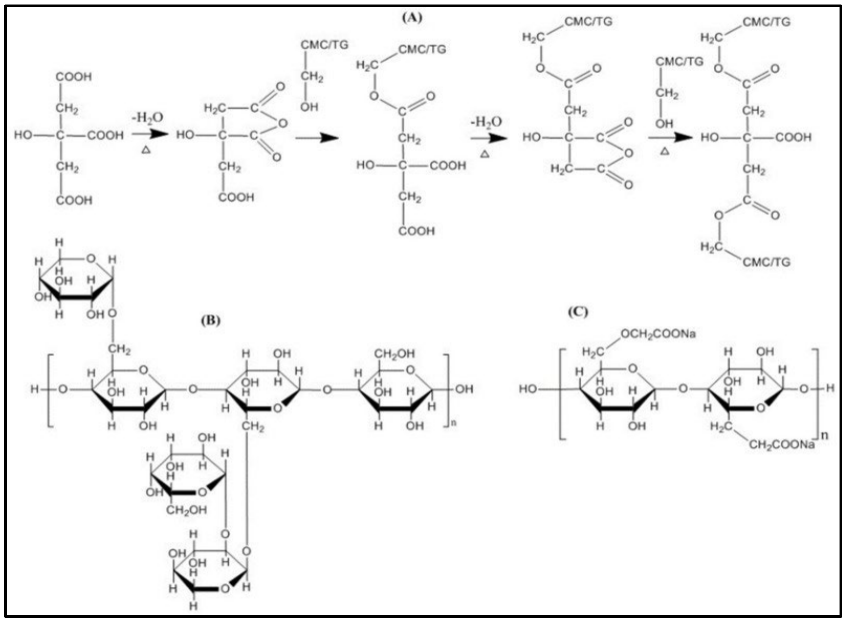

Figure 4. Mechanism of crosslinking reaction between citric acid and carboxymethyl cellulose. Figure from source 7).

Hypothesis

Alternative Hypothesis

The agar hydrogel will prove superior to the MEC and agar + MEC hydrogels in enhancing water retention.

Rationale: Based on agar's inherent properties from seaweed, it boasts a high water-absorption capacity by forming a gel matrix that can efficiently retain water. Its compatibility with various soil types and potential for reduced environmental impact make agar hydrogel a promising candidate for addressing water scarcity challenges in agriculture.

Null Hypothesis

There is no difference in water retention between agar, MEC, and agar + MEC hydrogels.

Methods

Materials

- Kitchen scale (accurate to the gram ±1)
- Agar powder ($4.00 USD)
- MEC powder ($10.00 USD)
- Citric acid powder ($7.00 USD)
- Water
- Kettle (for boiling)
- One-liter heat-resistant measuring cup
- Fork
- Spoon

- Thirty 90 x 15 mm petri dishes
- Paper towels
- Containers that can hold at least one cup of water
- Potting soil (without vermiculite and perlite)
- Small pots

Variables

Independent Variables

The independent variables include the hydrogels made from forty grams of agar, the hydrogels made from forty grams of MEC, and the hydrogels made from twenty grams of agar + twenty grams of MEC.

Dependent Variables

The dependent variables are the weights of the hydrogels + water.

Control Group

A control group where no hydrogel will be introduced in the "pot" testing environment (water + citric acid) will be our control group. This control allows the measure of the baseline water absorption, air-water loss, and soil water retention to be without the influence of any hydrogel. It serves as a reference point to compare the performance of the agar, MEC, and combined hydrogels.

Constant Variables

The constants in the hydrogels include ten grams of citric acid, five-hundred grams of boiling water, and seventy-five grams of potting soil. The data collection phase of the experiment implements several controls to ensure the reliability and validity of our findings.

Conditions

Room Temperature: Temperature plays a significant role in the physical properties of hydrogels. Variations in temperature could affect the rate of water absorption and the overall performance of the hydrogels. Keeping the temperature consistent across all experimental groups ensures that any differences observed in water absorption and retention are solely attributable to the inherent properties of the hydrogels and not influenced by temperature fluctuations.

Light Exposure: Similarly, light exposure is a key factor as it can impact the evaporation rates and overall behavior of the hydrogels. Inconsistent light conditions could introduce variability in the amount of water lost to the environment. By maintaining uniform light exposure, there is a controlled environment where any disparities in water absorption and retention can be confidently attributed to the hydrogel characteristics, rather than external factors like changes in light intensity.

Standardized Testing Intervals: All hydrogels need to be weighed at the same time every day. This control prevents potential time-dependent biases in the data and allows for accurate comparisons between different hydrogel formulations.

Procedure

The following is the procedure used to experimentally determine the water absorption and retention of biodegradable hydrogels of differing compositions.

Making the Biodegradable Hydrogels

Hydrogel	Agar (g)	MEC (g)	Citric Acid (g)	Boiling Water (g)
Agar	40	0	10	500
MEC	0	40	10	500
Agar + MEC	20	20	10	500

Figure 5. Recipe of each hydrogel, specifying the amount required of each independent variable.

- Mix the dry ingredients in the recipes in a heat-resistant measuring cup.
- Heat five-hundred mL of water in a kettle to boiling.
- Place the measuring cup with the dry ingredients on the scale and tare it.
- Pour the heated water into the measuring cup with the dry ingredients until the tared scale reads five-hundred grams.
- Take the measuring cup off of the scale and mix the solution for several minutes until all lumps are gone. The hydrogel mixture will be very thick and it will take a lot of mixing.
- When the hydrogel has been thoroughly mixed, place a petri dish on the scale and tare the scale. Spoon fifty grams of the hydrogel into a labeled petri dish. Repeat this step until all ten petri dishes for each recipe are filled.
- Follow the steps for the three recipes. There will be a total of ten petri dishes of each hydrogel recipe.
- Once cooled, put the lids on the petri dishes. Leave the hydrogels twenty-four hours before moving onto testing.

The decision to allocate eight samples each for agar, MEC, and a combination of both (along with four control samples) is based on several factors aimed at ensuring the experiment's statistical validity and reliability.

A sample size of eight for each hydrogel type and a sample size of four for the control group provides sufficient statistical power to detect meaningful differences in performance between the hydrogels and the control. Splitting the eight samples for each hydrogel type in two groups of four allows for replication within the experimental design. By testing each hydrogel type under two different conditions (air environment for water absorption and soil environment for water retention), the results can capture the variability in their performance, allowing for a comprehensive analysis of the hydrogels' capabilities.

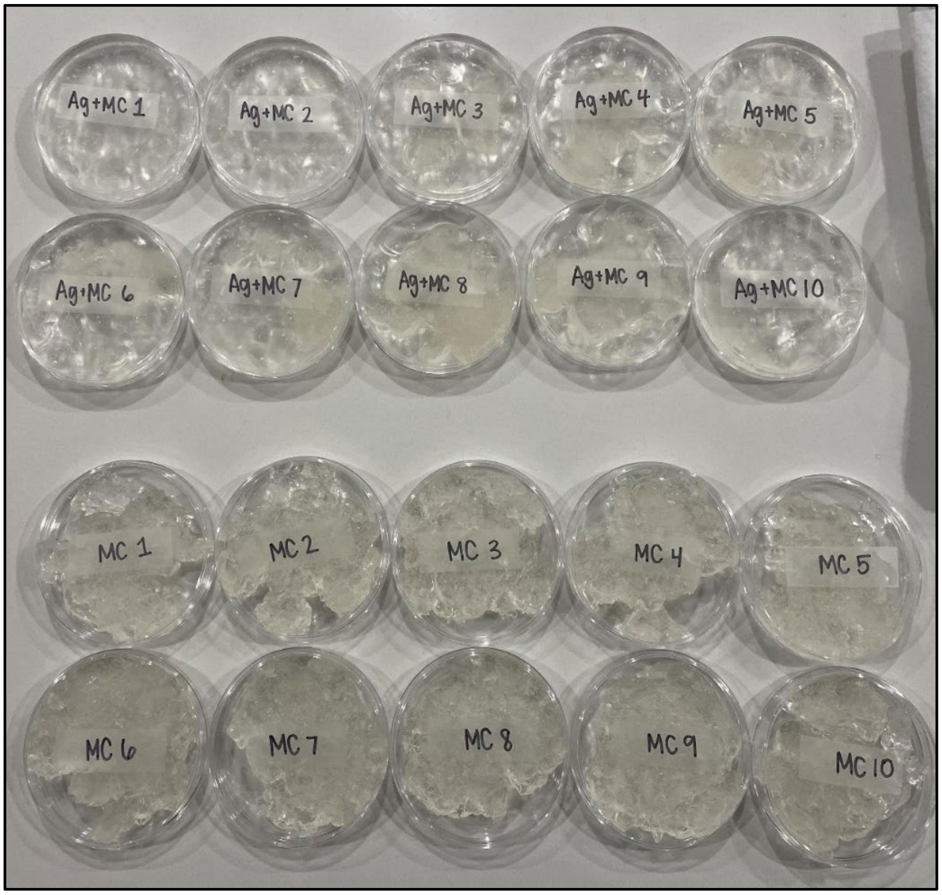

Figure 6. Image of hydrogels in petri dishes. Figure obtained by researchers.

Testing How Much Water the Biodegradable Hydrogels Can Absorb and How Quickly They Lose Water to Air Over Time

- Label four containers for each hydrogel recipe for a total of twelve containers. For example: Agar 1, Agar 2, Agar 3, Agar 4, MEC 1, MEC 2, etc.
- Record the weight of each empty container.
- Carefully remove one agar hydrogel from its petri dish and place it in the container labeled Agar 1. Repeat this step until one hydrogel is in each of the labeled containers. Make sure the labels match the type of hydrogel.
- Record observations about the consistency of each type of hydrogel.
- Weigh each hydrogel with its container for fourteen days and make observations.

Testing How Well the Biodegradable Hydrogels Retain Water in Soil Over Time

- Label four pots for each hydrogel recipe. For example: Agar 1, Agar 2, Agar 3, Agar 4, MEC 1, MEC 2, etc. Label four more pots Control 1, Control 2, Control 3, and Control 4. There are sixteen labeled pots in total.
- Using the tare scale, add seventy-five grams of potting soil to each pot.
- Add twenty-five grams of hydrogel to the twelve pots labeled for them.
- Add fifty mL of water to each of the sixteen pots.
- Get an initial weight for each prepared pot.

- Weigh each prepared pot daily for fourteen days and make observations.

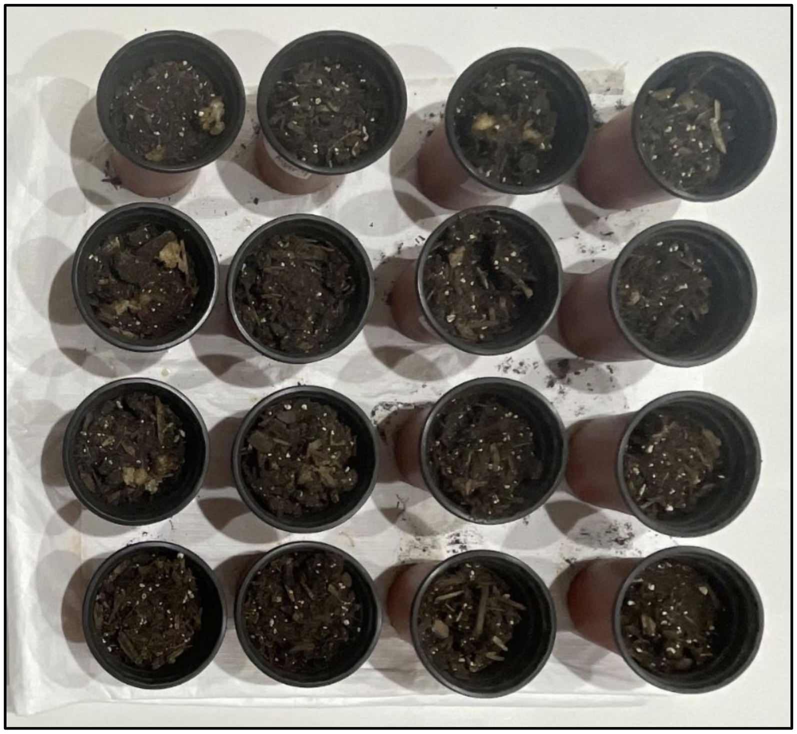

Figure 7. Hydrogels and water incorporated into pots of potting soil (soil environment). Figure obtained by researchers.

Safety and Ethical Considerations

- Proper personal protective equipment worn at all times: wearing a lab coat, safety goggles, and gloves to protect skin and eyes from potential hazards.
- Equipment handling: handle all laboratory equipment with care to prevent accidents or breakages, especially when dealing with boiling water.
- As agar and MEC are natural ingredients, they are not harmful to use in the laboratory or at home.
- Dispose of all experimental materials, including used hydrogels properly. It is advisable to recycle the plastic waste from the pots after testing. Disposal of tested materials into the environment is unethical as the effects are unknown and potentially harmful.

Results

Observation Factors

Visual Appearance

We observed the hydrogels for any changes in their appearance, such as changes in color, transparency, or surface texture. These changes could indicate alterations in the composition or structure of the hydrogels over time, which might affect their water absorption and retention properties.

Consistency and Texture

We assessed the hydrogels consistency and texture (specifically, their states of matter). These observations help to understand how the hydrogels are responding to water and whether they are maintaining their structural integrity.

Interactions with Surroundings

We observed how the hydrogels interact with their surroundings (soil and air). For instance, this includes noticing if the hydrogels adhere to the soil surface or if they formed a protective layer over it.

Daily Observations

Air Environment

Day 0:

- Agar: The agar hydrogel appears as a transparent liquid gel with a slight yellow hue; it looks pliable like a liquid.
- MEC: The MEC hydrogel appears transparent and firm, with a smooth surface texture. It appears slightly white in color.
- Agar + MEC: The combination hydrogel appears as a semi-transparent gel with firmer texture compared to agar alone.

Day 3:

- Agar: Some slight changes in color observed, with a slight increase in transparency. The surface texture remains smooth.
- MEC: No significant changes observed in color or transparency. The surface remains smooth and firm.
- Agar + MEC: No significant changes observed in color or transparency. The hydrogel remains firm.

Day 7:

- Agar: The agar hydrogel maintains its semi-transparency, but there's a slight increase in firmness observed. Surface texture remains consistent. It has decreased in size.
- MEC: The MEC hydrogel maintains its transparency and firmness. Surface texture remains consistent.
- Agar + MEC: The agar + MEC hydrogel maintains its structure, with no observable changes in appearance.

Day 14:

- Agar: The agar hydrogel continues to maintain its integrity, with no significant changes in appearance. It retains its liquid state. It is much smaller compared to day 0.
- MEC: Similar to previous days, no significant changes in appearance. The hydrogel retains its thick-gel state.
- Agar + MEC: Similarly, the hydrogel retains its semi-transparency and firm texture.

Soil Environment

Day 0:

- Agar: The agar hydrogel appears as a soft, semi-translucent substance within the potting soil. It blends well with the soil.
- MEC: The MEC hydrogel forms a firm, gel-like substance within the potting soil. It maintains its structure well.
- Agar + MEC: The agar + MEC hydrogel forms a semi-transparent gel within the potting soil. It appears to blend well with the soil.

Day 3:

- Agar: No significant changes observed. The hydrogel remains integrated with the soil.

- MEC: No observable changes in appearance. The MEC hydrogel remains integrated within the soil.
- Agar + MEC: No significant changes observed. The hydrogel remains integrated within the soil.

Day 7:

- Agar: The agar hydrogel continues to blend seamlessly with the soil, indicating good water retention.
- MEC: The MEC hydrogel maintains its firmness within the soil, indicating consistent water retention.
- Agar + MEC: The agar + MEC hydrogel maintains its structure within the soil, indicating good water retention.

Day 14:

- Agar: The agar hydrogel still appears integrated with the soil, maintaining its water retention properties.
- MEC: The MEC hydrogel continues to hold its form within the soil, showing no signs of degradation.
- Agar + MEC: Similar to previous observations, the hydrogel remains integrated with the soil, indicating consistent water retention properties.

Measurement

Weighing the hydrogels, containers, and water daily provided quantitative data on the water absorption and retention capabilities of the hydrogels. By measuring the weight of the hydrogels and their components before and after soaking in water or being placed in soil, we can calculate the amount of water absorbed or lost by the hydrogels over time. This data is crucial for assessing the performance of the hydrogels in terms of water retention, which is directly relevant to their potential application in sustainable agriculture. Additionally, monitoring the weight of the hydrogels and their components allowed us to track any changes in mass that might occur due to factors such as evaporation or degradation. This information is crucial for understanding the stability and durability of the hydrogels over time, which is essential for their practical use in agricultural settings where they may be exposed to various environmental conditions. Through our methods of observation and measurement we were able to gather both qualitative and quantitative data that will allow for valid and reliable analysis of the hydrogels' performance.

Raw Data

After conducting a series of trials, the following results were obtained.

Air Environment

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Hydrogel	Empty Container Weight (g)	Before Soaking: Hydrogel + Container Weight (g)	After Soaking: Hydrogel + Container Weight (g) on Day # (on row below)														
			Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
Agar 1	15	65	52	34	33	29	27	23	23	23	23	23	23	23	23	23	23
Agar 2	15	45	35	23	23	23	22	21	20	20	20	20	20	20	20	20	20
Agar 3	15	49	39	24	23	22	21	21	21	21	21	21	21	21	21	21	21
Agar 4	15	50	40	25	24	23	21	21	21	21	21	21	21	21	21	21	21
MEC 1	15	64	110	88	80	78	67	56	38	30	26	24	24	22	21	21	21
MEC 2	15	66	139	113	100	86	70	59	50	39	33	30	27	25	22	22	22
MEC 3	15	61	120	100	92	80	72	60	42	36	30	27	24	22	22	22	22
MEC 4	15	61	139	110	87	72	60	57	48	39	33	30	25	22	21	21	21
Agar + MEC 1	15	60	111	85	69	58	42	30	25	23	20	20	20	20	20	20	20
Agar + MEC 2	15	58	131	103	72	60	52	40	36	28	23	23	23	21	21	21	21
Agar + MEC 3	15	54	99	75	62	50	36	30	24	22	20	20	20	19	19	19	19
Agar + MEC 4	15	56	94	72	64	52	43	32	21	20	20	20	20	20	20	20	20

Figure 8. Weights before and after water soaking over fourteen days in the air environment (includes weights of containers and hydrogels).

Soil Environment

Pot	Weight (g) on Each Day # (on row below)														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Agar 1	141	100	94	92	88	84	82	81	88	88	87	86	86	86	86
Agar 2	142	101	95	94	90	85	83	82	82	82	82	82	82	82	82
Agar 3	141	100	93	90	87	82	81	80	80	80	80	80	80	80	80
Agar 4	140	99	92	89	86	83	81	80	80	80	80	80	80	80	80
MEC 1	149	95	91	88	84	83	82	82	82	82	82	82	82	82	82
MEC 2	150	94	90	89	87	84	83	82	82	82	82	82	82	81	81
MEC 3	150	94	90	88	87	84	83	82	82	82	82	82	82	82	81
MEC 4	150	94	90	89	87	85	83	82	82	82	82	82	82	82	82
Agar + MEC 1	150	100	98	96	92	88	86	84	84	84	84	84	83	83	83
Agar + MEC 2	150	97	95	93	90	87	82	81	81	81	81	81	80	79	79
Agar + MEC 3	151	97	95	93	90	87	85	83	83	83	83	83	83	82	82
Agar + MEC 4	150	102	99	93	86	85	82	82	82	82	82	82	82	82	82
Control 1	135	92	91	88	84	81	80	80	73	70	70	70	68	67	67
Control 2	140	98	93	89	86	80	79	79	75	73	73	71	71	71	71
Control 3	125	82	80	78	77	75	74	74	70	68	68	68	68	68	68
Control 4	129	86	85	82	80	79	78	77	72	72	72	71	71	71	71

Figure 9. Weights after soaking soil and hydrogels with water for each trial over fourteen days in the soil environment (includes weights of pots).

Processed Data and Analysis

Sample Calculations (for Agar 1)

<u>Testing How Much Water the Biodegradable Hydrogels Can Absorb:</u>

$$\text{Hydrogel and Container Weight} - \text{Empty Container Weight} = \text{Hydrogel Weight Before Soaking}$$

$$65\text{ g} - 15\text{ g} = 50\text{ g}$$

$$\text{Soaked Hydrogel and Container Weight} - \text{Empty Container Weight} = \text{Hydrogel Weight After Soaking}$$

$$52\text{ g} - 15\text{ g} = 37\text{ g}$$

$$\frac{\text{Hydrogel Weight After Soaking} - \text{Hydrogel Weight Before Soaking}}{\text{Hydrogel Weight Before Soaking}} * 100$$

$$= \text{Relative \% Water Absorbed}$$

$$\frac{37\text{ g} - 50\text{ g}}{50\text{ g}} * 100 = -26.0\%$$

After calculating the relative percent of water absorbed for each sample of hydrogel, we averaged the four percentages for each type of hydrogel to determine the average relative percent of water absorbed for each type of hydrogel.

<u>Testing How Quickly Biodegradable Hydrogels Lose Water to Air Over Time:</u>

$$\frac{\text{Day n Weight} - \text{Day 0 Weight}}{\text{Day 0 Weight}} * 100 = \text{Relative \% Change in Water}$$

$$\frac{34\text{ g} - 52\text{ g}}{34\text{ g}} * 100 = -34.6\%$$

After calculating the relative percent change in water in the air environment for each day for each sample of hydrogel, we averaged the four percentages for each type of hydrogel for each day in order to create a graph to depict the average relative percent change in water in the air environment for each type of hydrogel over the fourteen days.

Testing How Well the Biodegradable Hydrogels Conserve Water in Soil Over Time:

$$\frac{\text{Day n Weight} - \text{Day 0 Weight}}{\text{Day 0 Weight}} * 100 = \text{Relative \% Change in Water}$$

$$\frac{100\text{ g} - 141\text{ g}}{141\text{ g}} * 100 = -29.1\%$$

After calculating the relative percent change in water in the soil environment for each day for each sample of hydrogel, we averaged the four percentages for each type of hydrogel for each day in order to create a graph to depict the average relative percent change in water in the soil environment for each type of hydrogel over the fourteen days.

Air Environment

Hydrogel	Empty Container Weight (g)	Before Soaking		After Soaking		Relative % Water Absorbed	Average Relative % Water Absorbed
		Hydrogel + Container (g)	Hydrogel (g)	Hydrogel + Container (g)	Hydrogel (g)		
Agar 1	15	65	50	52	37	-26.0	-29.3
Agar 2	15	45	30	35	20	-33.3	
Agar 3	15	49	34	39	24	-29.4	
Agar 4	15	50	35	40	25	-28.6	
MEC 1	15	64	49	110	95	46.9	66.9
MEC 2	15	66	51	139	124	71.6	
MEC 3	15	61	46	120	105	64.1	
MEC 4	15	61	46	139	124	84.8	
Agar + MEC	15	60	45	111	96	56.7	61.4
Agar + MEC	15	58	43	131	116	84.9	
Agar + MEC	15	54	39	99	84	57.7	
Agar + MEC	15	56	41	94	79	46.3	

Figure 10. Average relative percent of water absorbed by each type of hydrogel in the air environment.

Hydrogel	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
Agar 1	0	-34.6	-36.5	-44.2	-48.1	-55.8	-55.8	-55.8	-55.8	-55.8	-55.8	-55.8	-55.8	-55.8	-55.8
Agar 2	0	-34.3	-34.3	-34.3	-37.1	-40.0	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9
Agar 3	0	-38.5	-41.0	-43.6	-46.2	-46.2	-46.2	-46.2	-46.2	-46.2	-46.2	-46.2	-46.2	-46.2	-46.2
Agar 4	0	-37.5	-40.0	-42.5	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5
MEC 1	0	-20.0	-27.3	-29.1	-39.1	-49.1	-65.5	-72.7	-76.4	-78.2	-78.2	-80.0	-80.9	-80.9	-80.9
MEC 2	0	-18.7	-28.1	-38.1	-49.6	-57.6	-64.0	-71.9	-76.3	-78.4	-80.6	-82.0	-84.2	-84.2	-84.2
MEC 3	0	-16.7	-23.3	-33.3	-40.0	-50.0	-65.0	-70.0	-75.0	-77.5	-80.0	-81.7	-81.7	-81.7	-81.7
MEC 4	0	-20.9	-37.4	-48.2	-56.8	-59.0	-65.5	-71.9	-76.3	-78.4	-82.0	-84.2	-84.9	-84.9	-84.9
Agar + MEC	0	-23.4	-37.8	-47.7	-62.2	-73.0	-77.5	-79.3	-82.0	-82.0	-82.0	-82.0	-82.0	-82.0	-82.0
Agar + MEC	0	-21.4	-45.0	-54.2	-60.3	-69.5	-72.5	-78.6	-82.4	-82.4	-82.4	-84.0	-84.0	-84.0	-84.0
Agar + MEC	0	-24.2	-37.4	-49.5	-63.6	-69.7	-75.8	-77.8	-79.8	-79.8	-79.8	-80.8	-80.8	-80.8	-80.8
Agar + MEC	0	-23.4	-31.9	-44.7	-54.3	-66.0	-77.7	-78.7	-78.7	-78.7	-78.7	-78.7	-78.7	-78.7	-78.7

Figure 11. Relative percent change in water on each day for all trials over fourteen days in the air environment.

Hydrogel	Day														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Agar	0	-36.2	-38.0	-41.2	-44.7	-47.4	-48.1	-48.1	-48.1	-48.1	-48.1	-48.1	-48.1	-48.1	-48.1
MEC	0	-19.1	-29.0	-37.2	-46.4	-53.9	-65.0	-71.7	-76.0	-78.1	-80.2	-82.0	-82.9	-82.9	-82.9
Agar + MEC	0	-23.1	-38.0	-49.0	-60.1	-69.5	-75.9	-78.6	-80.7	-80.7	-80.7	-81.4	-81.4	-81.4	-81.4

Figure 12. Average relative percent change in water on each day for each type of hydrogel over fourteen days in the air environment.

Soil Environment

Hydrogel	Relative % Change in Water on Each Day # (on row below)														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Agar 1	0	-29.1	-33.3	-34.8	-37.6	-40.4	-41.8	-42.6	-37.6	-37.6	-38.3	-39.0	-39.0	-39.0	-39.0
Agar 2	0	-28.9	-33.1	-33.8	-36.6	-40.1	-41.5	-42.3	-42.3	-42.3	-42.3	-42.3	-42.3	-42.3	-42.3
Agar 3	0	-29.1	-34.0	-36.2	-38.3	-41.8	-42.6	-43.3	-43.3	-43.3	-43.3	-43.3	-43.3	-43.3	-43.3
Agar 4	0	-29.3	-34.3	-36.4	-38.6	-40.7	-42.1	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9
MEC 1	0	-36.2	-38.9	-40.9	-43.6	-44.3	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0
MEC 2	0	-37.3	-40.0	-40.7	-42.0	-44.0	-44.7	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3	-46.0	-46.0
MEC 3	0	-37.3	-40.0	-41.3	-42.0	-44.0	-44.7	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3	-46.0
MEC 4	0	-37.3	-40.0	-40.7	-42.0	-43.3	-44.7	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3
Agar + MEC 1	0	-33.3	-34.7	-36.0	-38.7	-41.3	-42.7	-44.0	-44.0	-44.0	-44.0	-44.0	-44.7	-44.7	-44.7
Agar + MEC 2	0	-35.3	-36.7	-38.0	-40.0	-42.0	-45.3	-46.0	-46.0	-46.0	-46.0	-46.0	-46.7	-47.3	-47.3
Agar + MEC 3	0	-35.8	-37.1	-38.4	-40.4	-42.4	-43.7	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.7	-45.7
Agar + MEC 4	0	-32.0	-34.0	-38.0	-42.7	-43.3	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3	-45.3
Control 1	0	-31.9	-32.6	-34.8	-37.8	-40.0	-40.7	-40.7	-45.9	-48.1	-48.1	-48.1	-49.6	-50.4	-50.4
Control 2	0	-30.0	-33.6	-36.4	-38.6	-42.9	-43.6	-43.6	-46.4	-47.9	-47.9	-49.3	-49.3	-49.3	-49.3
Control 3	0	-34.4	-36.0	-37.6	-38.4	-40.0	-40.8	-40.8	-44.0	-45.6	-45.6	-45.6	-45.6	-45.6	-45.6
Control 4	0	-33.3	-34.1	-36.4	-38.0	-38.8	-39.5	-40.3	-44.2	-44.2	-44.2	-45.0	-45.0	-45.0	-45.0

Figure 13. Relative percent change in water on each day for all trials over fourteen days in the soil environment.

Hydrogel	Average Relative % Change in Water on Each Day # (on row below)														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Agar	0	-29.1	-33.7	-35.3	-37.8	-40.8	-42.0	-42.7	-41.5	-41.5	-41.7	-41.8	-41.8	-41.8	-41.8
MEC	0	-37.1	-39.7	-40.9	-42.4	-43.9	-44.7	-45.2	-45.2	-45.2	-45.2	-45.2	-45.2	-45.4	-45.6
Agar + MEC	0	-34.1	-35.6	-37.6	-40.4	-42.3	-44.3	-45.1	-45.1	-45.1	-45.1	-45.1	-45.4	-45.8	-45.8
Control	0	-32.4	-34.1	-36.3	-38.2	-40.4	-41.2	-41.4	-45.1	-46.4	-46.4	-47.0	-47.4	-47.6	-47.6

Figure 14. Average relative percent change in water on each day for each type of hydrogel over fourteen days in the soil environment.

Air Environment Results Graphs

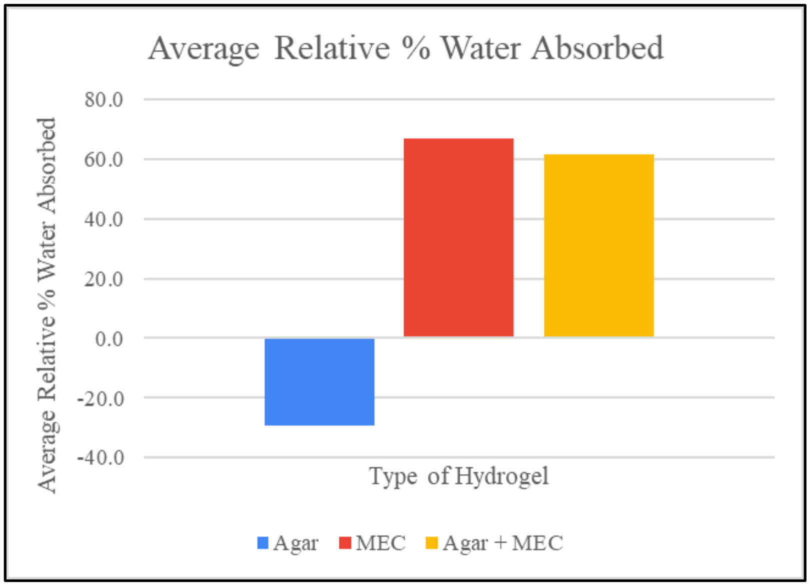

Figure 15. Bar graph representing the average relative percent water absorbed for each type of hydrogel in the air environment.

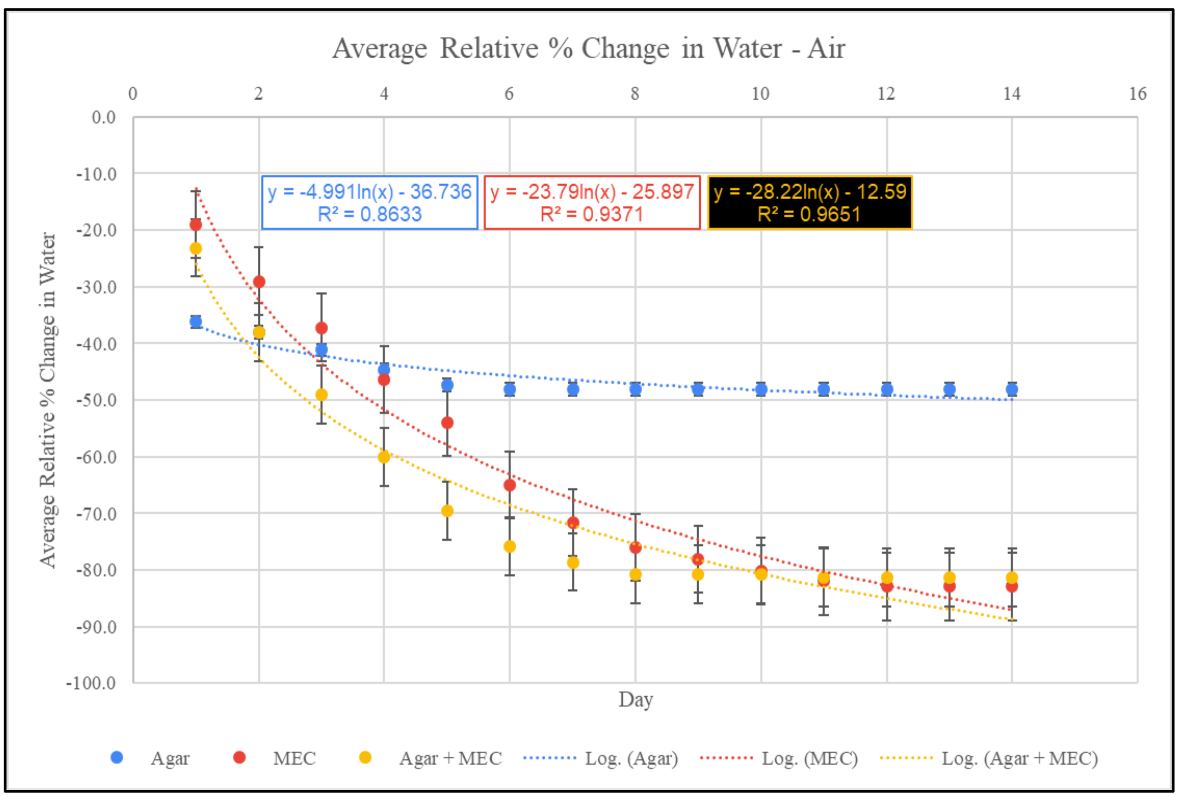

Figure 16. Graph with logarithmic fittings representing the average relative percent water absorbed for each type of hydrogel over fourteen days in the air environment.

Soil Environment Results Graph

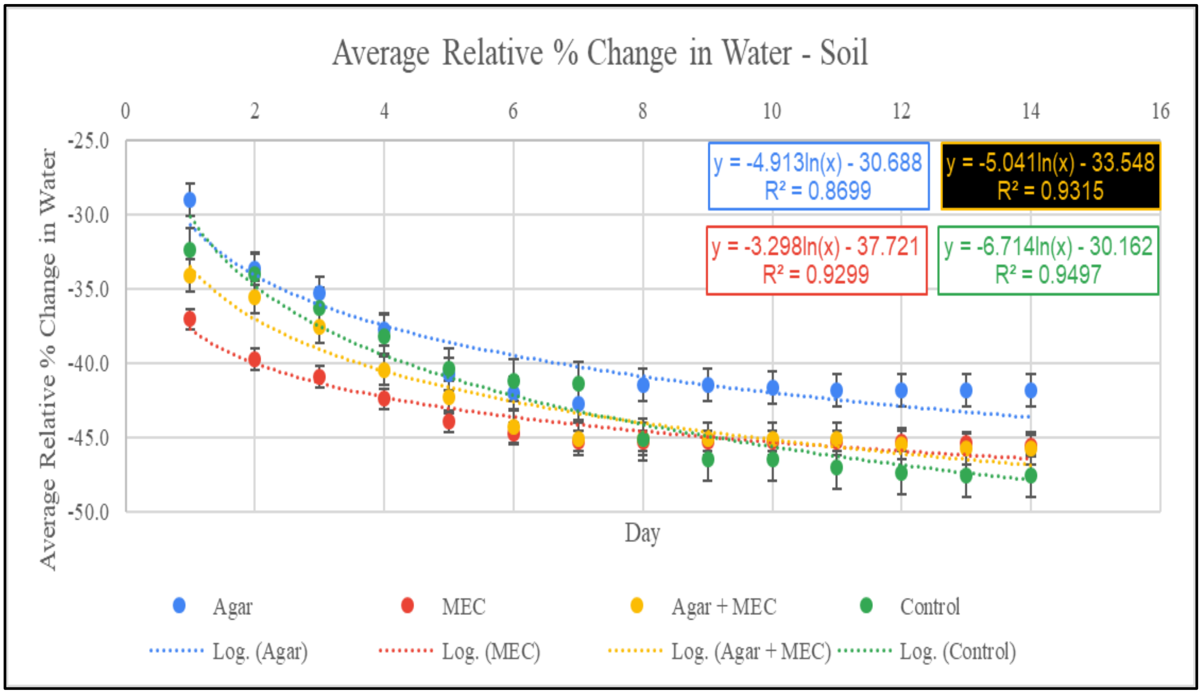

Figure 17. Graph with logarithmic fittings representing the average relative percent water absorbed for each type of hydrogel over fourteen days in the soil environment.

Analysis of Graphs

We used a logarithmic fitting for the graphs for the following reasons:

Wide Range of Values: The data for each hydrogel's performance contains varying values and logarithmic fittings allow for the visualization and analysis of data that may encompass orders of magnitude difference values more effectively than linear fittings.

Exponential Behavior: When graphed, the data exhibits exponential behavior. Therefore, logarithmic fittings will help to model and understand this behavior accurately.

To ensure the reliability of the data, standard error bars are included in the graphs. This allows for the measurement of the variability of the sample mean from the population mean, providing insights into the consistency and accuracy of our results. By incorporating standard error bars we have the ability to show the reliability of the data, compare the performance of different hydrogels under the conditions, and assess the statistical significance of observed differences.

R^2 or the coefficient of determination is a statistical measure that determines the proportion of variance in the dependent variable that can be explained by the independent variable. The R^2 values are all in between 0.85-1.00, indicating that the logarithmic value fits the data well for these reasons. We evaluated this value for each trend line on the graphs and found that all the logarithmic fits are reliable to the data.

High Goodness of Fit: R^2 values close to 1 indicate that a large proportion of the variability in data is explained by the logarithmic model. With our R^2 values being greater than 0.85, the logarithmic model provides a strong representation of the relationship between the variables.

Reliable Predictions: High R^2 values signify that the models' predictions are reliable and consistent with the observed data. This is crucial for drawing accurate conclusions and making predictions.

Overall Results

When the hydrogels were soaked in water and tested for water absorption in the environment of air, the MEC hydrogel performed the best with an average 66.9% relative percent water absorbed. When the hydrogels were added to pots of soil and tested for how well they conserve water in soil, the agar hydrogel performed best with the least amount of water lost (an average of -36.5% relative change in water).

Conclusion

The agar hydrogel was able to conserve water in a pot of soil the best. Although it performed the worst out of the hydrogels when tested solely in the environment of air, we believe that it will work the best in a true agricultural environment. This is due to it not firming into a gel unlike its counterparts. When undergoing the initial trials for the air environment portion of the experiment, the agar hydrogel did not retain the majority of the water it was soaked in due to its state and therefore its tendency to be evaporated. MEC is used in more commercial processes than agar due to its affinity to form gels. Agar also has this tendency but not to the strength of MEC. Therefore, with further testing of differing agar hydrogel recipes, one that forms the most gel-like substance would lose less of its mass to air due to it not evaporating. In a real agricultural environment, the hydrogel's ability to form gels quickly is not crucial to the hydrogel's ability to retain water.

Discussion

Future experiments could explore optimized combinations and ratios of agar and MEC to maximize water absorption and retention. Transitioning from controlled conditions to field trials is crucial for real-world validation. Monitoring hydrogel stability over extended periods in soil will contribute to understanding their long-term impact on water conservation. Extrapolating this research into agriculture would lead to changes into the development of recipes for hydrogels.

Real-world applications could include the integration of hydrogels into technology, specifically an app that alerts farmers when to replace/add more hydrogel for irrigation. Additionally, there could be a calendar feature that predicts how much/when the hydrogel needs to be replaced. This would allow farmers to plan ahead of time and estimate how much hydrogel they need to order per month, reducing their expenses.

Limitations

Despite the promising potential of biodegradable hydrogels in agricultural practices, several limitations constrain the conclusions drawn from this research. The measurement uncertainty of ±1 gram, while manageable, introduces a degree of variability in the data, potentially impacting the precision of water retention measurements. This margin of error could obscure subtle differences between the hydrogel formulations and their effectiveness, particularly in a controlled experimental setting where even small deviations can influence overall results. Thus, using a scale with a lower uncertainty (ex. ± 0.001 g) leads to more accurate results.

Moreover, the relatively small sample size—eight samples for each hydrogel type and four for the control group—limits the statistical power of our findings. Larger sample sizes generally enhance the accuracy and reliability of estimates, reducing the risk of erroneous or misleading conclusions. While the initial results indicate the viability of hydrogels as a sustainable solution for soil water retention, further research with larger sample sizes is necessary to validate these findings and ensure their generalizability across diverse agricultural contexts.

Additionally, the duration and scope of the study were confined to a relatively short observation period and specific experimental conditions. Long-term studies are necessary to fully understand the performance and environmental impact of biodegradable hydrogels over multiple growing seasons and under varying climatic conditions. This extended analysis would provide insights into the degradation processes of the hydrogels and their interactions with different soil types and crop species.

The experimental setup, while controlled, does not entirely replicate the complex interactions present in natural agricultural environments. Factors such as soil microbiota, varying weather conditions, and crop-specific water needs play crucial roles in the real-world application of hydrogels. Our study provides a foundational understanding, but field trials are essential to validate laboratory findings and assess practical feasibility on a larger scale.

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