INTERNATIONAL BACCALAUREATE BIOLOGY EXTENDED ESSAY

Does the volume of water (1 liter, 0.75 liters, 0.50 liters, 0.25 liters) in a "Deepwater culture" farming setup affect the rate of growth of Anethum graveolens in biomass over one month period?

Subject: Biology

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Introduction:

Earth is losing its rich soil year after another. Because of the scarcity of water, deforestation, and diverse means, our caring planet loses 36 billion tons of soil per year [1]. Bestowing to a study by the University of Basel, the European Commission, and CEH (Centre for Ecology & Hydrology) if we consider the importance of agriculture, to feed all human beings, we need to get ahead of the inevitable disaster of not being able to get fertile soil. This is extremely crucial, considering the increasing human population and the rapidly decaying resources.

Water-based farming is a greater alternative developed to solve the "lack of soil" problem. Via this technique and using specially designed chemicals, we can produce some vegetables without the need for soil. This system is called Hydroponic Farming. Hydroponics is a way to skip the soil, sub in a different material to support the roots of the plant, and grow crops directly in nutrient-rich water. There are multiple approaches to designing hydroponic systems, but the core elements are essentially the same.[2] With hydroponic farming and hydroponic systems, the soil is replaced with nutrient-rich water instead. Normally, plants mostly use water for 3 purposes: thermal (helps the plant regulate its own temperature), solvent (carries the nutrients needed), for photosynthesis (required for sustaining life) Without a doubt, the essential ingredient for a plant is water.

There are many types of Hydroponic Farming systems. One of the easiest and most effective types of Hydroponic Systems is the Deep Water Culture (DWC). As it may easily be understood from the name, in DWC, plant roots are preserved in a well-oxygenated solution full of nutrients and water 24/7. This is unlike other hydroponic techniques like the Ebb and Flow, Aeroponics, Drip System, in which plants are watered on a constant basis.[3]

In DWC however, the roots are submerged deep in the water. The reservoir that contains the plants holds a "good" amount of water. It is generally assumed that the more water there is, the more stability in the nutrient solution and the less maintenance and monitoring required. [3]

However, this technique comes with its flaws, our water reserves are draining rapidly. According to the Mulieres company, around 25 million kilograms of harmful and non-biodegradable cleaning products are used each day globally, which causes contamination of around 182,5 billion liters of drinking water per year. [4] This causes a lot of usable and clean water to be wasted and contaminated. Therefore, other than soil, there is also a water shortage. Also when we consider the impacts of global warming, specifically drought, decrease in usable water amount and its effect on plant growth is crucial to investigate. Since one important alternative to soilless farming is shown as "hydrophobic farming", how scarcity of water affects harvested resources, thus the amount of food production with the method is valuable to study to understand the feasibility of the practice and investments in the method with the ongoing changes in the world.

In sum, the world's water sources are draining rapidly. This is why I chose to test the effect of the change in the volume of water in Hydroponic Farming, on the growth of *Anethum graveolens* plants indicated by biomass after 30 days.

I chose this method because DWC needs less monitoring and is easy to set up. There are even predesigned WRP sets to obtain in Turkey, cheaper, and quite easy to set up.

Figure 1: Commercially available WRC set, used for the experiment

In my experiment, I have used 4 sets of identical setups with different amounts of water in order to observe the effect of water on growth in hydroponic culture (other parameters being constant). *Anethum graveolens* seeds were chosen due to the growing fast and being semi resistant to both warmth and cold according to “Consulta Plantas. [5]

Research Question

Since I wonder if the growth rate of the *Anethum graveolens* seeds indicated by biomass (g) will be affected by the volume of water in a deep water culture system and aim to study on its effect on yield, my research question is **“*Does the volume of water (1 liter, 0.75 liters, 0.50 liters, 0.25 liters) in a “Deepwater culture” farming setup affect the rate of growth of Anethum graveolens in biomass over one month period?*”**

Hypothesis

If we use the same amount (By volume) of nutrition chemicals in a DWP set up with different volumes of water, it can be hypothesized that the volume of water (1 liter, 0.75liters, 0.5 liters, 0.25 liters) will affect the growth of *Anethum graveolens* indicated by biomass in aquatic farming set up over a month.

Method Development and Planning

Upon some research, I have realized that there are several different types of soilless farming setups: the wick system, deep water culture, nutrient film technique, flood and drain, drip systems, aeroponics[6]. All the systems work in their unique ways. And most of them have air pumps or other contraptions which add more variables to the experiment.

On the other hand, the Deep Water Culture System (DWC) is easier and more effective. As I wanted to experiment by myself, I chose the deepwater system. It works by submerging the plant's roots inside the nutrition-rich water within the container. It mainly needs a water tank, chemicals, and some cloth to attach the roots and the water. Plants hover above the water and are connected by a cloth. The main variable is the volume of water. I easily found a predesigned setup kit for DWC.

The kit that I bought had a manual stating that a 1-liter amount of water was suggested for the given tank. Due to the single connection between the nutrients and the plants, I decided to lower the water amount by 25%, 50%, and 75%. But I tried to keep the contact surface as similar as possible. This way it will be possible to observe the effect of the amount of water while keeping other parameters constant.

All cloth pieces touch the seed routs with a 2.5 cm^2 surface area and it's the same size for water contact. I will install setups with different amounts of water (1000ml, 750ml, 500ml, 250ml) But for all setups the same ribbons will be used. Below 250 ml, ribbons will be short. This is because this amount of water is my lower limit.

I have planned to use bottled water. (with phosphorus, potassium, calcium, magnesium, sulfur) I choose the water company based on which company was approved by the health department for where I live. [7]

The company we obtained the tools from suggested we use between 10 and 20 seeds per slot to successfully grow healthy plants. I decided to use 15 per slot for my experiment. Thus having a median number would represent the best usage of the culture, in terms of interaction between the seeds.

Figure 2: Seeds Used

They also need temperatures between 15 and 21 degrees[8]. I measured the temperature to be 20 degrees inside the balcony which is ideal. The dill seeds also require direct sunlight. The planned place for the farming setup gets 10 hours of sunlight per day. I set up the systems where there is the most sunlight on my balcony.

Figure 3: Finding a sunny and warm environment

According to a British Company Valliant, a normal room temperature should be between 20 and 22 degrees celsius.[9] I have checked our balcony's temperature and its average is 20.8^{0}C

To measure the growth, I thought of measuring the height first as it was easy. But once I acknowledged branching, I changed the indication method to biomass.

I will measure the lengths of the *Anethum graveolens* seeds using a standard 30 cm ruler at the very beginning in order to try to choose similar size seeds. Although I will measure the lengths of plants during the experiment for side information, the main parameter is **biomass.**

At the end of the experimentation period I will measure the Biomasses of all plants. Biomass is the total weight of living plant and animal material, including above and below ground. In my study I would have to calculate the total weight of the plants including the body and branches. One of the basic ways of calculating the biomass of a plant is to obtain the dry weight of an organism (in this case our plant) This weight will be a rough approximation of the amount of biomass. To do this, I have read some papers. But in fact some posts in web forums[38] were much more practical. Therefore when the experiment ends, I will drain excess water from the roots. Then place the plants in a paper bag (to prevent from burning). Afterward dry them in an oven at $45^{0\ C}$ for 24 hours. After drying, I will measure their weight on a precision scale. I will repeat the measurement 3 times for each plant.

According to The Texas A&M AgriLife Extension Service, the average growth time for *Anethum graveolens* is 90 days but they state that whenever the dill seeds are grown, they can be harvested. My mother used to grow dill seeds for cooking purposes, From her trials and experiences I've decided to test for only one month of growth.[10]

I ordered the necessary parts from the ***Hidroponik Türkiye.***[11] When I received and opened the cargo, I was sent four identical plastic boxes that have specially made holders for me to place the sprouted *Anethum graveolens* seeds inside, a water holding area large enough to fill it with one liter of water, and a liter of nutritious plant solution to mix in with the water.

Variables

Independent variables	The amount of water given to the *Anethum graveolens* seeds in liters (1 liter, 0.75 liters, 0.50 liters, 0.25 liters)
Dependent variables	The height of the *Anethum graveolens* plants in cm
Controlled variables	The position of the farming set up; in order to get some levels of sunlight and temperature (a thermometer will be used to moderate the temperature daily. The type of container they are placed in. The amount of nutritious solution the plants get (a measuring cup will be used.) How the seeds are prepared, the seeds will be prepared at the same time, within the same temperature and humidity. The shape and model of the ruler were used to calculate the height (in cm) of the *Anethum graveolens* plants. The temperatıre is between 20 to 22 Celsius. A cotton cloth that absorbs and transmits water well.

I chose these controlled variables because these are the most basic needs for any plant to grow. These variables can easily be controlled by positioning the setup correctly and a few tools such as a thermometer, psychrometer, and measuring cup. The room temperature will be controlled by a wall-mounted thermometer. To control the amount of sunlight I will put the systems next to each other. The humidity will be measured by a psychrometer. The source of the water will be the same for water quality. The number of nutrients will be the amount that is recommended by the officials. The same *Anethum graveolens* seeds will be used. 15 *Anethum graveolens* seeds will be used for each system.

Materials List

-Four identical soilless farming setups including the nutrients.

- Total of sprouted dill grass 480 seeds. (8 slots/setup, 4 setups, 15 seeds/slots)

-A thermometer

-An Oven

-Paper bag for plants

-A metal ruler.

-Chemicals are used to nourish the vegetables.

-Dedicated notebook to note the observations.

Method:

1) A sustainable environment, which gets enough sunlight, enough water, the right mixture of a nutritious solution, for the growth of the *Anethum graveolens* will be set up.
2) The soilless farming device will be set up. The system has a water tank and a place for *Anethum graveolens*. There will be continuous contact between *Anethum graveolens and water.*

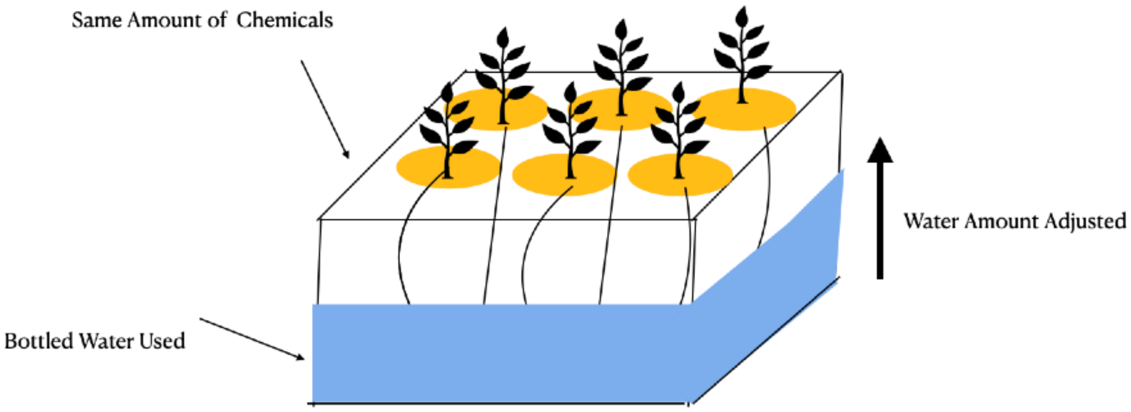

Figure 4: Set up of the DWC

3) The 15 already sprouted *Anethum graveolens* seeds will be placed inside each slot of each setup. (4 setup with 8 slots in each setup)

Figure 5: Seeds Placement

4) In each setup 1000 / 750 / 500 / 250 milliliters of water will be put inside respectively.

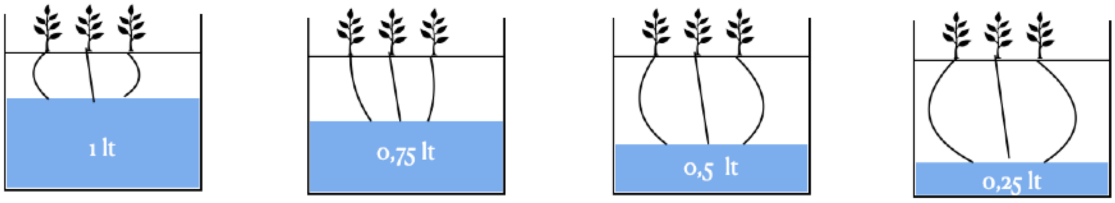

Figure 6: Adjusting Water

5) Every other day, all the controlled variables for the sprouted Anethum graveolens seeds will be checked.

6) After 30 days, the biomass of the sprouted *Anethum graveolens* seeds will be collected.

7) After collection, excess water will be drained from roots. Plants will be put in a paper bag and will be dried in an oven at $45^{0\ C}$ for 24 hours. After drying, their weight will be measured on a precision scale.

8) All measurements will be recorded in the notebook.

9) Finally, all data will be analyzed and findings will be concluded.

Data Collection and Processing

Data listed below is the calculated average of the data gathered. Table 1 shows the average length (just to show its correlation with biomass) and biomass data itself. Table 2 is showing the raw biomass data (the focus of my study) for different water amounts.

	Length of *Anethum graveolens* (including all the branches) in cm (∓0,05cm)	Biomass of *Anethum graveolens* in grams (∓0,05g)
250ml of water	-	**-**
500ml of water	17.28	**13.49**
750ml of water	22.11	**18.60**
1000 ml of water	34.49	**29.97**

Table 1: Water amount, length and Biomass data

	Biomass of the sprouted seeds after 30 days (g)		
Trial	**(500 ml water test)** Biomass in grams (∓0,05g)	**(750 ml water test)** Biomass in grams (∓0,05g)	**(1.000 ml water test)** Biomass in grams (∓0,05g)
1	13.6	18.6	28.3
2	13.8	18.7	27.9
3	12.8	16.8	28.6
4	14.1	18.9	28.4
5	12.5	17.6	29.3
6	12.7	15.9	27.8
7	13.9	19.6	24.9
8	12.5	18.2	32.3
9	13.1	18.6	33.4
10	13.5	18.4	33.8
11	14.6	21.2	32.1
12	14.1	20.1	30.8
13	13.6	19.2	30.4
14	13.8	18.3	32.3
15	12.8	17.3	34.5
16	12.6	17.6	30.1
17	14.3	17.2	29.1
18	14.1	18.5	28.3
19	13.6	18.2	29.6
20	13.7	18.33	27.5
Average	13.49	18.6	29.97

Table 2: Biomass of the sprouted seeds after 30 days for different water amounts.

After the experiment's month had ended, the most noticeable two can be summarized as follows: First of all, there was a lower limit on the minimum water amount that is necessary to get any yield. Below that level of water, it is not possible to have any yield. The second finding was that there is a positive correlation between the water amount and the number of branches each *Anethum graveolens* plant had.

The first group which gets 250 ml of water, never sprouted. Out of the 20 trials I had, only one has survived with a very thin main body with no other branches. Therefore the average biomass of the first test can be assumed to be "0".

In the second group which got 250 ml of water, nearly all of them had longer main bodies while having little to no branches at all, their main bodies were the thickest out of all other groups. Where they gained from the body, they lost from the branches, on average they had 3 branches per plant. They had smaller leaves in general than the other test groups.

The third group, which got 0.750ml of water took both properties of the second and the fourth groups. They had a sturdy main body just like the second group while having an average of 7 branches per plant. The branches were longer while having fewer leaves. Most of the ribbons were colored gold metallic.[12]

The fourth group which got the recommended amount of water of 1 liter, all of them had short but very thick main bodies, all of them had excessive amounts of branches and leaves, The branches were half the main body with a lot of leaves; The leaves were quite similar to what you could get from a market. The ribbons were heavily damaged, all of them needed replacements, the old replaced ones were "cafe noir"[13] colored.

Figure 7: Results of 1000ml vs 500ml water usage.

Analysis

After an experiment taking more than a month, my findings are very clear and can be easily categorized.

First of all, as shown by many other studies [14,15,16], Hydroponic Farming works! Even in an apartment or on a balcony, one can grow a plant. That's probably the most important finding. If we imagine more controlled environments and mass production, this system can change the world. A study by Pimental and Giampietro showed that productive fertile soil is a nonrenewable, endangered ecosystem.[17] Therefore, practical soilless farming is vital.

The second finding is, the performance of hydroponic farming (DWC) depends on the right amount of water. We all know the value of water and aim to use it wisely. But my experiment shows us that waiving water creates productivity problems.

The third finding is, there is a meaningful relationship between the growth rate of a plant's biomass and the amount of water used (figure8). In the figure, uncertainty bars stating (∓0,05g) error are also shown. At first glance it seems like there is a positive relationship. As the amount decreases, the biomass growth rate worsens. And below 250 ml of water, growth totally disappears. In the following chart one can easily see the effect of water amount on biomass.

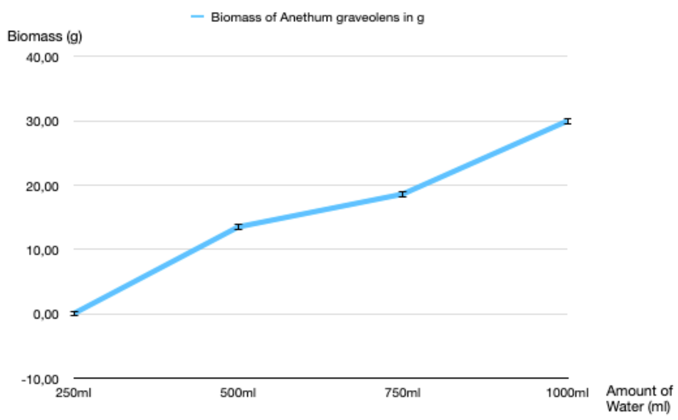

Figure 8: Effect of water usage on Biomass

We knew from the manual of the setup I used, that the optimum amount of water to be used as standard should be 1 liter. Therefore, I consider the growth and weight results obtained with 1 liter of water as a reference. Then I have changed the amount of water to make an analysis(Table 1). Let's evaluate the results from the table1 to measure how much biomass growth is damaged when we reduce the reference water amount.(Table 4)

Amount Of Water	Biomass (in grams) (∓0,05g)	Decrease in amt. of Water	Decrease in The Biomass
500ml	13,49	%33	%26,40 decrease
750 ml	18,33	%25	%38,84 decrease
1000ml	29,97	(Reference Amount)	(Reference Biomass)

Table 4: Change in Biomass Due to Change in the amount of water

The 250ml water usage results are discarded due to no growth. 500ml, 750ml and 1000ml water used trial results are compared by taking 1000ml as reference. That is, the change (decrease percentage) in the average biomass has been calculated due to the change in the water amount from 1000ml to 750ml and from 750ml to 500 ml.

In Table4, we can see that by reducing the 1000ml reference water amount by 25% to 750ml of water, the biomass has decreased by 38.84% (other factors being equal). When I reduce the water amount by 33% from 750 to 500 ml (which means 50% decrease from the reference value 1000ml), I see that the biomass is 26,40% lower than 750ml. If we look at our reference point (1000 ml) as the amount of water is reduced by 50% (to 500 ml), the growth of biomass decreases by 54.99%. As I mentioned in the first stages of the experiment, no growth was observed in the amount of water below 250ml. From here, all other factors being equal, biomass decreases as the amount of water decreases, but below a certain amount of water, there is zero growth.

To reach these results, I have made 20 tests for each of the 4 different water tanks. That means, 80 tests have taken place. For the first tank with 250 ml, there was no outcome. But in other tanks containing 500ml, 750ml and 1000ml respectively, there were growing plants. Although the conclusion is briefed above, I had to test the statistical meaning of the data. For this, I have used the ANOVA test.

ANOVA test is a way to find out if survey or experiment results are significant. In other words, it helps you to figure out if you need to reject the null hypothesis or accept the alternate hypothesis. You're testing groups to see if there is a difference between them.

It may be calculated one-way or two-way.[18] These values refer to the number of independent variables. I have used a one-way test because in my experiment the only independent variable is the amount of water.

ANOVA stands for Analysis of variance and tells you if there are any statistical differences between the means of three or more independent groups. One-way ANOVA is the most basic form. And the description just fits my data.

With my data and single-factor ANOVA Test, results are as follows:

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0.500 ml	20	269,7	13,485	0,417132
0.750 ml	20	367,23	18,3615	1,370803
1.000 ml	20	599,4	29,97	6,068526

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2868,618	2	1434,309	547,6929	6,12E-38	3,158843
Within Groups	149,2728	57	2,61882			
Total	3017,891	59				

Table 3: Anova Test Results

As the P-value is less than the value of Alpha which is 0,05 ($p<0,05$), our results are statistically meaningful. That is, the average biomass data of all three groups are statistically different.

Conclusion

My research question was "***Does the volume of water (1 liter, 0.75 liters, 0.50 liters, 0.25 liters) in a "Deepwater culture" farming setup affect the rate of growth of Anethum graveolens in centimeters over one month?***" The result of my studies supports my hypothesis that **the amount of water (1 liter, 0.5 liters, 0.25 liters) will affect the growth of *Anethum graveolens***.

After a month-long experiment, first of all, I have proved that the Deep Water Culture farming system works efficiently and its success depends on the amount of water. Soilless farming is possible and has many advantages.

In my study, I accepted my hypothesis, thus approving that change in volume of water effects the biomass. When viewed from the farthest point, biomass means food. Therefore, we see that the amount of water is a factor affecting food production, even in soilless agriculture. Saving water is of course important, but it comes at a very clear cost. Soilless farming eliminates the need for fertile soil, but sufficient water is a must. As I explained above in detail and with numerical values, if the required amount of water decreases, the plant still grows. However, there are two important details: First, the decrease in the amount of water below the ideal rate negatively affects the development of the plant in terms of biomass. Second, water below a certain amount leads to zero growth.

Discussion and Further Studies

Alternative farming techniques and the amount of biomass that is produced are crucial for the world, specifically regions like the North coast of Turkey, The Black Sea Region. Since the area is geographically mountainous and has limited fields suitable for agriculture, excessive precipitation, and sudden snow melts. There has been a great struggle against erosion since the 1970s, and in the Black Sea region, it has been almost successfully solved.[39] On the other hand, according to many sources, the situation is not very encouraging for our country as a whole. Apart from the special situation of the Black Sea Region , the loss of land is widespread and dangerous: Turkey loses about two-thirds of the amount of land lost by all European countries every year. The annual loss is around 168 million tons.[40] When we combine the loss of soil problem in Turkey (Black Sea Region in particular) and Hydroponic Agriculture (which is the subject of my study) we come across an interesting conclusion, an increase in the necessity of water in alternative techniques. The success of the Netherlands in alternative farming shows how crucial the other methods are[41]. Thus due to causes like climate change and pollution decrease in water not only affects traditional agricultural methods but other methods that are being used to enhance productivity and it is meaningful to understand how it will affect biomass as it is done in this study.

For my study, to measure the results of the experiment comfortably and not to reach confusing side results, I only changed one parameter: The amount of water used. For different amounts of water, there were the same amount of nutrition chemicals. For further studies it may be meaningful to analyze the effect of changing the amount of chemicals according to the amount of water, keeping the same amount of seeds for each setup.

I proved in my study that a decrease in water amount worsens the biomass growth rate. I have measured in 250 ml scales. That is a change in the amount of water at the rates of 25%, 50%, 75%. In future studies, it will be possible to reach more precise results if much narrower scales are used.

Although my experiment is an IB project, it aims to examine a very vital topic. The fertile land on earth is both limited and declining. Parallel to this, the world population is increasing rapidly. Therefore soilless agriculture is of vital importance. However, even if soilless agriculture becomes widespread, we will still need plenty of water. In this study, I tried to examine how much water can be saved. After all, the change in the variable we measure here as “biomass” means “food" for billions of people. There is a dilemma between the cost of water and the cost of food, and it should be discussed in future studies how much we, as humanity, can afford to give up.

According to the results that I have found, I can say that, if farmers can successfully grow plants via Deep Water Culture, those hectares of farmlands can be compacted into five to ten-storied buildings. This may change the necessity of ownership for expensive and limited Farmlands.

The common usage of DWC will also change the need for big and expensive machinery like harvesters and tractors. Such a change may reduce costs, change in the industry, affect usage of resources, pollution, financing, etc. Another advantage of DWC would be “shortening the supply chain". Because of the possibility of agricultural production even within the city, the need for transportation of such products from remote areas will decrease. This also will have a positive effect on fuel consumption, time spent on logistics, and the environment.

In sum, Hydroponic farming in general and the Deep Water Culture (DWC) System, in particular, have so many advantages for the future of farming, watering, logistics, pollution, and cost.

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Figures

Figure 1: Commercially available WRC set, used for the experiment

Figure 2: Seeds Used

Figure 3: Finding a sunny and warm environment

Figure 4: Set up of the DWC

Figure 5: Seeds Placement

Figure 6: Adjusting Water

Figure 7: Results of 1000ml vs 500ml water usage.

Figure 8: Effect of water usage on Biomass Growth

Tables

Table 1: Water amount, length and Biomass data

Table 2: Biomass of the sprouted seeds after 30 days for different water amounts.

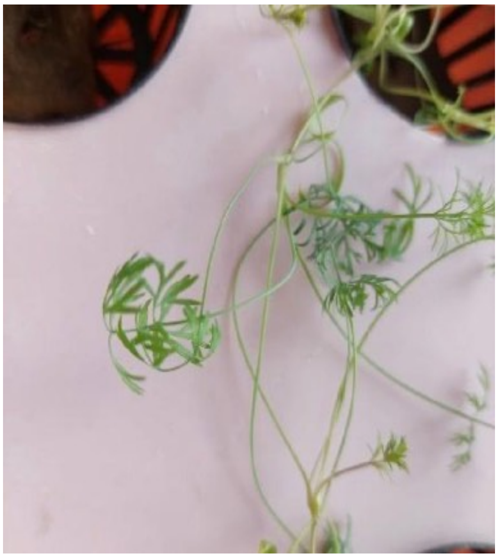
Table 3: Anova Test Results

Table 4: Change in Biomass Due to Change in amount of water

Appendix

Water remained in the “500ml setup”

Water remained in the “1000ml setup”



The product of “1000ml setup”

The product (!) of “250 ml setup”