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GROWING PLANTS, GROWING MINDS WITH EDUCATIONAL AQUAPONICS SYSTEMS

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SHORT ABSTRACT

Our planet needs innovative solutions to the problem of water management and water protection. Young people of my age long for a more enjoyable, more practical, experience-based education. Both problems can be tackled at the same time by the cultivation of educational aquaponics systems, which provides teenagers with the opportunity to acquire versatile knowledge by experimental learning while increasing their environmental awareness with water management and protection in the focus. In my work I successfully designed an educational aquaponics system, which proved to be capable of functioning. Therefore, in my essay I present the results of my research on aquaponics systems and discuss their introduction to the framework of secondary school education.

LIST OF ACRONYMS

AOB Ammonia-Oxidizing Bacteria

DO Dissolved Oxygen

EC Electrical Conductivity

NH_3 Ammonia

NH_4^+ Ammonium ion

NO_2^- Nitrite

NO_3^- Nitrate

NOB Nitrite-Oxidizing Bacteria

Ppm Unit of measurement, Abbreviation of Parts Per Million

RAS Recirculating Aquaponics System

1. INTRODUCTION

When you get to know how the idea of the "Growing Food, Growing Minds with Educational Aquaponics Systems" project was born, you will clearly see it is not a typical problem solving project that builds on a hypothesis. It is more like a learning process.

We were learning about nitrification in biology class when I came across aquaponics, the idea of using the nitrogen cycle in a creative way, which captivated my imagination. So without substantial knowledge of plant requirements, nutrition or fish physiology, I embarked on the project and built my own experimental system. It had a simple purpose: to challenge myself and gain experience in something new.

Later, however, after building and operating the system, continuous research and problem solving, I found that my work covers a wider range of subjects and while I am doing it I can learn a lot in an autodidactic way based on my own experience while enjoying the whole process.

It was at this stage that I discovered the social and environmental benefits of using aquaponics in agriculture (König, Junge, Bittsánszky, Morris, Kőmíves, 2016; Goddek, Delaide, Mankasingh, Ragnarsdottir, Jijakli, Thorarinsdottir, 2015). Then came the idea of linking the problem of the monotony and lack of first-hand experience typical of regular classes at school and the global problems of water demand and water pollution by introducing small aquaponics systems to education (Hart, Webb, Hollingsworth, Danylchuk, 2014), breaking out of the routine of the "conventional" classroom environment and immersing students in the world of experimental learning while increasing their water awareness and introducing them to the complex operation of a promising future food-producing technology (Hart, Webb, Danylchuk, 2013; Genello, Fry, Frederick, Li, Love, 2015). This is how the objective of my research had evolved: to design a sustainable educational system and achieve this idea. Accordingly, I divided the present essay into two parts: in the first part I put forward the theory and present the results of my research done on my experimental system, then I discuss the design and operation of a well-functioning educational system. While in the second part I present the steps of introducing it to education.

1.1. AQUAPONICS IN A NUTSHELL

Aquaponics is a food producing method that integrates aquaculture with hydroponics (Diver, Rinehart, 2000). In other words, it combines fish breeding with soil-less crop producing. This combination makes it possible to naturally satiate the plant's nutrient requirement and therefore avoid artificial nutrient solutions used in hydroponics. In addition, ammonia is toxic to the fish and it would poison them if allowed to accumulate within the water supply.

Aquaponics systems are dependent upon the naturally occurring nitrogen cycle to make nutrients available to crops.

The system utilises waste ammonia produced by the fish as a by-product of respiration. Nitrification being a two-step oxidation process, firstly the AOB type bacteria convert waste ammonia that has been produced by the fish into nitrites, then the NOB type bacteria convert it into nitrates, which is an available form of nitrogen for plants (United States Environmental Protection Agency, 2002).
According to the following equations:

$$2NH_4^{+} + 3O_2 \rightarrow 2NO_2^{-} + 4H^{+} + 2H_2O$$

$$2NO_2^{-} + O_2 \rightarrow 2NO_3^{-}$$

OR

$$NH_3 + O_2 \rightarrow NO_2^{-} + 3H^{+} + 2e^{-}$$

$$NO_2^{-} + H_2O \rightarrow NO_3^{-} + 2H^{+} + 2e^{-}$$

1.2. WATER RELATED BENEFITS OF USING AQUAPONICS IN AGRICULTURE

Aquaponics is already commonly used in various parts of the world: the biggest agricultural systems can be found in North America[1], England[2] and Switzerland[3]. These companies usually sell both the crops and fish, often connecting it with vertical farming using towers, grow lights, solar panels and greenhouses.
Aquaponics is an innovative approach to water management as well as water protection (Junge, König, Villarroel, Komives, Jijakli, 2017).
As the same water is used for raising fish and growing food, this technology can provide 8 times more food per acre[4] using 1/6th of the water[5] compared to traditional agriculture, which means about 90% less water is used.
Furthermore, as the biological processes ensure enough nutrients aquaponics can protect our rivers and lakes from water pollution by eliminating the use of artificial nutrient solutions, fertilizers and pesticides.
Naturally, this is still not a perfect solution as building can be complicated and expensive, operation requires professional skills and is electricity-intensive, and potentially connecting them to solar panels involves further expenses. However, In view of their benefits, they could be the future of aqriculture.

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[1],FarmedHere, Nelspn And Pade, Superior Fresh LLC
[2] GrowUp Farms Ltd
[3] UrbanFarmers AG
[4] A unit of land aera equal to 4046.85 m^2
[5] Calculated by Nelson and Pade Ict. using their own data

2. METHODS AND RESULTS OF SYSTEM DESIGNING AND MANAGING

2.1. EXPERIMENTAL NON-RECIRCULATING SYSTEM

I started my aquaponics project by setting up this aquaponics system. The design of the system is very simple. It consists of two parts: the aquarium that contains dechlorinated water and provides a habitat for two guppies that are fed with simple mosquito larvae, and a growing bed on the top which is filled with dried clay growing media and has holes in the bottom.

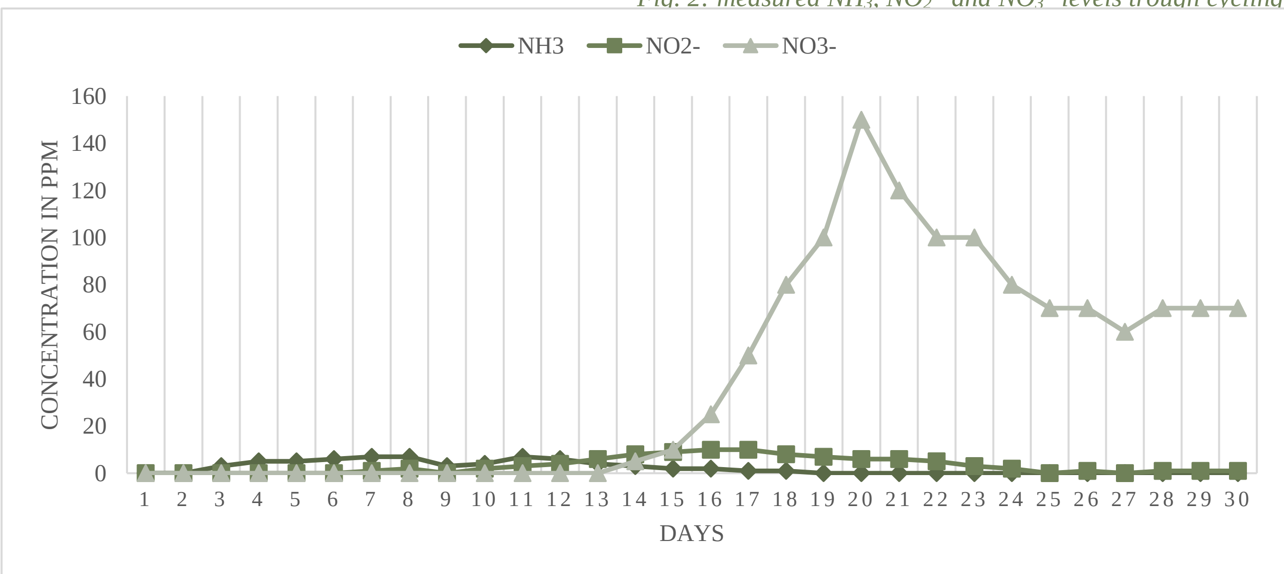
Ths system operated from December 20th to March 15th and was used as basis for the measurements, observations and conclusions discussed below providing an opportunity for me to gain new experience and acquire the knowledge that later inspired me to start my educational project.

Fig. 1: Experimental Non-Recirculating System

2.1.1. CYCLING

By setting up this aquaponics system I could monitor the onset of the nitrogen cycle. During a period of 30 days, from December 20th to January 18th, I measured the NH_3, NO_2^- and NO_3^- levels daily using my school JBL Ammonium/Ammonia and JBL EasyTest 6in1 water tests. The approximate values of concentration change by time are presented in a table (see App. 7.1.) and are shown on this chart[6].

Fig. 2: measured NH_3, NO_2^- and NO_3^- levels trough cycling



[6] As the data is unknow between measuring points, the linking of them only made for better visualization.

I used the plantless cycling method where only the fish were in my system. The onset occurred completely naturally through the natural colonisation of the bacteria. First the ammonia level increased, then, as it decreased, the NO_2^- level rose, and as both dwindled, the NO_3^- level increased. The eventual decreases happened because of the water charges that were done in order to avoid water toxication.

After about 25 days the balance set in at an average of 60 ppm of no3, 1 ppm of no2 and zero ammonia. The values are in ppm corresponding to mg/l, which means if the value is 1 ppm, 1 mg can be dissolved in one litre (1000g) of water. In this case it means that in my tank which contains an average of 9 litres of water 0.00011 g nitrite and 0.0066 g nitrate are dissolved.

This relatively high amount of nitrates can be promising at first but, after the balance sets in, the lower the better, because it means the plants could take up the nutrients.

2.1.2. IMORTANT FACTORS AND TESTS PERFORMED

Using the same 6in1 water test used for measuring nitrites and nitrates, I could also monitor the chlorine, pH, hardness and alkalinity levels.

Since chlorine is toxic for the fish, the only ideal value is zero. For this reason, I performed dechlorination before setting up the system and before water inputs by boiling the water.

The ideal pH is calculated by considering the ideal pH ranges for fish, plants and bacteria, respectively (Tyson, Simonne, White, Lamb, 2004). General freshwater fish prefer a slightly acidic pH ranging from 5.5 to 7.5, but it could go up to 9; values differing from these may cause stress and lead to an increased risk of death. For an appropriate nutrient uptake, plants also prefer a slightly acidic environment, usually between a pH of 6 and 7. Bacteria prefer slightly alkaline conditions, but they are very adaptable, and they die only in extremely acidic conditions. Based on these considerations, a neutral or slightly lower pH is the ideal, approximately between 6.5-7.2.

Water hardness is a measure of positively charged Ca^{2+} and Mg^{2+} ions. Total hardness is the summation of the concentrations of Ca^{2+} and Mg^{2+}, as expressed in ppm $CaCO_3$. Hardness can range from soft (0–75 ppm) to very hard (>300 ppm). As dissolved calcium in the water influences osmoregulation, it can relieve stress in fish; for guppies the levels should be maintained between 50 and 250 ppm. The value at baseline was 300 ppm, which I later improved by adding long time boiled water when changing and refilling the water.

Alkalinity refers to the ability to resist changes in pH, called solution buffering capacity. It is a measure of the total concentration of bases in a liquid and is expressed as the equivalent concentration of $CaCO_3$. As pH is a key to stable aquaponics system operation, alkalinity should be maintained at 100 ppm $CaCO_3$ or above, so the relatively high value (about 300 ppm) measured in my system is completely acceptable.

Other important factors are the amount of solid waste and available nutrient requirements, DO, water temperature, light intensity and EC, which will be discussed further on.

2.1.3. NUTRIENT DEFICIENCY AND MANEGEMENT PROBLEMS

After the cycling I introduced chives and rooted sweet potato into my system, which contain high concentrations of available nitrogen and other essential nutrients in their tubers. The chives grew huge quickly and had an intensive taste (see App. 7.2.), while the sweet potato developed a complex root and sprouts in two weeks (see App. 7.3.).

When I introduced other plants from seedlings, they were stagnant for 2-3 days, then the symptoms of nutrient deficiency started appearing. Similarly, I failed to grow plants from seeds.

This can easily be explained by the almost 200-year-old Liebig's law of minimum, where he states that plants need many essential nutritious elements to grow healthily and if only one of these elements is deficient, plant growth will be inhibited, even if all the other essential nutrients are available in abundance. In this case it means that despite high amounts of available nitrogen, deficiency of some meso- and micro-elements is still a problem that cannot be overcome (Bittsánszky, Uzinger, Gyulai, Mathis, Junge, Morris, Benzion, Kőmíves, 2016). His statement can be easily illustrated by the image of a barrel where the essential nutrients are the staves of the barrel and the water is the yield and quality.

Fig. 3: Liebig's Barrel

Management also started to cause problems. The system required cleaning and scheduled water changes, because it became dirty and discoloured by the high amounts of unprocessed solid waste.

2.2. RECIRCULATING EDUCATIONAL SYSTEM

Fig. 4: Recirculating Educational System

After a careful designing process, during which I collected what I had learnt from my experimental system, I studied the large-scale agricultural systems (Bright Argotech, 2012-2015, Backyard Aquaponics, 2006-, GrowUp Urban Farms, 2018-).

On the strength of the knowledge thus acquired, I started building a recirculating educational system.

The building of the system took place on March 16th when I used the same water used for the previous system and followed prearranged plans (see App. 7.4.).

In this system the two main parts, the grow bed and the tank, are separated and the only connection is through a water cycle maintained by a water pump.

This water pump keeps the approximately 9 litres of water in continuous recycling ensuring freshness and by means of capacity control retains water level at 60% in my growing bed.

An oxygen pump is also used to provide adequate DO levels and satisfy the organisms' oxygen requirement.

2.2.1. USING WORMS – THE SYSTEM'S NEW CYCLE

After some nutrition-focused research, I found the solution to the problem of nutrition deficiency and water pollution using composting worms (Newell, 2016; Rakocy, Masser, Thomas M. Losordo, 2006). The composting worms live in the grow bed and break down the solid waste that could not be processed by the bacteria, thus cleaning the water and making nutrients available to crops. The most commonly used worms for composting are redworms, but other rarer species are suitable too. I used European nightcrawlers (*Dendrobaena* sp.), the same which is used for fishing and can be found in any local fishing shop. I introduced 23 worms into my system. Thanks to the high amount of oxygen provided by the oxygen pump, the originally overland worms could successfully adapt to this watery environment and consequently added a composting cycle to the nitrogen cycle base. The system's new bio-cycle inhabited by the two guppies, nitrifying bacteria, worms and plants can be seen in the following figure.[7]

[7] Proper figure using own pictures except the photo about the nitrifying bacteria which is owned by https://noticiasdelaciencia.com

Fig. 5: System's New Bio-Cycle

2.2.2. MESUREMENTS AND OPERATION

The operation process is much easier than that of the previous system. The fish need to be fed once daily using mosquito larvae and homemade lettuce feed prepared by drying. The weakly tasks include water refill because of evaporation and the performance of JBL water tests to ensure appropriate functioning of the system. I did not find any difference between the previous and the current systems in terms of pH, hardness, alkalinity, chlorine, ammonia and nitrite, but the previous cycled system's average 60 ppm of nitrate decreased to 40 ppm. On the basis of these data I assumed that the difference might be caused by the plants' better nutrient uptake; this, however, cannot be stated as this level depends on a number of factors.

For a more effective monitoring I started using Parrot Flower Power plant growth sensors[8]. These sensors are able to connect to a phone using Bluetooth connection and the measured values can be read by the use of a special application, which also makes references and advice available. With the help of these sensors I was able to measure the temperature and got an average value of 20 C°, which is considered acceptable. I also monitored light intensity (measured in lux), which proved to be slightly low at 120 but could be increased to 150 by moving the system closer to the window. In addition, I measured electrical conductivity, which reflects on the level of nutrients taken up as plants usually take up nutritional elements in the form of ions, and got an average of 0.8 ds/m which is fairly good for an aquaponics system.

[8] https://www.parrot.com/global/connected-garden/parrot-pot#parrot-pot

2.2.3. PRODUCTION

The stabilized factors and the new nutrient source made it possible to successfully germinate sorrel, different types of lettuce and parsley, and also sorrel and parsley from seedlings.

The seedlings acclimatized well and within just a few days grew substantially.

In the case of the sorrel seeds I tested the efficiency of aquaponics on germination speed. To do this, I germinated the seeds under three different conditions: Subject 1 was germinated under aquaponic conditions in pots with holes on their sides (see App. 7.5.), which were then placed in the grow bed; Subjects 2 and 3 were planted in plain unfertilized soil the only difference being that for Subject 3 cotton was used to promote germination (see App. 7.6.).

The height and development of the plants were monitored. The observation period started on April 2nd and finished on April 12th, when each subject had reached a height of 2 cm (see App. 7.7.).

The results by day are shown in the following table:

Development	Height	Subject No.1	Subject No.3	Subject No.2
Germination time	-	2	3	4
Sprouting from the soil	2-3 mm	3	4	6
Appearance of leaves	7-8 mm	4	6	7
Significant growth stem	2 cm	6	10	10

Fig. 6: Results of the Germination Speed Experiment

As can be seen, each subject sprouted from the soil on a different day, with No.1 being the first and No.2 the last. After sprouting, No. 1 grew even faster. No further difference could, however, be observed between No. 2 and No. 3 so it seems that cotton could only promote initial growth. Subject No.1 eventually reached the 2 cm height four days earlier (see App. 7.8.), which clearly demonstrates the efficiency of aquaponics and the appropriate functioning of the system.

3. INTRODUCTION TO EDUCATION

In order to start my educational line, I organised mini lectures on April 5th where I presented the basics of aquaponics, nitrogen cycle and symbioses through my system. Altogether there were 11 classes organised for students aged 15 to 18 years in groups of 12 to 15; in this way, approximately 150 students could participate.

I started my lectures by introducing aquaponics, continued by showing the biological cycle of my system on a figure (see App. 7.9.), and then explained the technical aspects of the system. After that, I talked about the daily measurements I had done and their importance, here I talked about the cycling process for which I created an interactive game where I reproduced some of the water tests performed at a larger scale (see App. 7.10.). On this the NH_3, NO_2^- and NO_3^- were drawn and just as in the original test the darker colour meant the higher concentration and the lightest represented the lowest. The task was to put them in chronological order on the basis of my explanation and diagram After this I explained the benefits of the system and shared my own learning experience.

Fig. 7: Playing with the Interactive Game

At the end of the session the students had the opportunity to take a closer look at my system and ask questions. They asked questions about the building process, the costs, but the most common questions they asked were “If it has all these benefits, both agricultural and educational, why don’t we use it in schools and agriculture?” and “Why don’t we know about it?” The most reliable answer is that it being a really new method that has not been fully tested yet, it has not become widespread and therefore its use in education could not even be considered. In agriculture, as a well-functioning system requires a relatively high level of investment and resources are limited, companies are afraid to embark on such projects.

On this day my school also organised its traditional event for students majoring in science called TETA. This meeting includes presentations by 11th graders as well as invited speakers. This year, I. as a 9th grader got the opportunity to present too. In my presentation I talked about aquaponics in general, then discussed my system, and talked about its building and management.[9]

[9] The live of the meeting can be rewind on our school’s Facebook page, where my presentation in Hungarian can be seen from 27:30.
https://www.facebook.com/mzsgsze/videos/2660677334005913/

4. DISSCUSION

With all the results from my measurements and monitoring I was able to design a well-functioning system as seen “methods and result of system designing and managing” part.

When I introduced this system to education, I got positive feedback from students and teachers alike. What teachers appreciated most was the initiative, the opportunity of peer learning, and visualisation of the system. Students emphasised the innovative approach. Some of them were particularly interested in the project and asked further questions after the end of the presentation and are now planning to build their own aquaponics system. The presentation I held at the annual scientific meeting won the Audience’s Award too.

However, this is not the end of the project. The system has just been introduced into education and a lot has to be done to make it an integrative part of the educational process. Also, it can be continuously improved and can serve as a basis for further research for a more effective management. Furthermore, I already have ideas how to use it for greywater recycling and also to produce substantial amounts of foodstuff by building systems at a larger scale.

5. ESSENTIALS

5.1. INTRODUCTION OF THE AUTHOR

My name is Eszter Kun. I am 15 years old and I attend Zsigmond Móricz Secondary School in Szentendre, Hungary. Although I have been interested in science from a very early age, this year has been a turning point as I started my first year in a Biology and Chemistry class, where I have been able to fully pursue my interests and participate in projects promoting environmental consciousness, like the Grow project[10]. I have also gained experience doing research work and joined the Association of Student Researchers. In addition to my scientific interests, I like doing sports, visual arts and spending time in nature. As I see it now, in the future I want to have a job related to biochemical or chemical engineering.

5.2. STATEMENT OF WORK

All the research, monitoring, measurement and evaluation were performed by me. My mentor for this project is my chemistry teacher Barnabás Sárospataki, who revised the present text professionally. Linguistic revision was performed by my English teacher Dr Zsuzsanna Kiss.

I also got professional help with plant physiology from Anett Póss at the University of Debrecen. Furthermore, I contacted Dr Gabor Gyulai, retired professor and department head, who is one of the few people in Hungary who has done research in aquaponics. For the water analyses I used our schools’ water tests, and the plant growth sensors are also from Anett Póss.

[10] https://growobservatory.org/

5.3 LONGER SUMMARY

Our planet needs innovative solutions to the problem of water management and water protection. Young people of my age long for a more enjoyable, more practical, experience-based education. Both problems can be tackled at the same time by the cultivation of educational aquaponics systems, which provides teenagers with the opportunity to acquire versatile knowledge by experimental learning while increasing their environmental awareness with water management and protection in the focus. Therefore, the aim of my "Growing Plants, Growing Minds with Educational Aquaponics Systems" project was to design a sustainable educational system and introduce it to education.

To achieve this goal, I first set up an experimental system, where I grew plants of low nutritional requirement, documented the onset of the nitrogen cycle, measured essential parameters, and monitored arising problems.

After tackling these problems, I summarised my experience and extended my research to include the design and building of an educational system where, due to my improvements, I was able to grow plants of higher nutritional requirement and carry out further measurements. What is more, by conducting further experiments, I was able to demonstrate the efficiency of the system.

Finally, I made an attempt at introducing the idea of aquaponics systems to education by sharing my experience with fellow students in a series of mini presentations and a major one at our school's annual scientific event.

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7. APPENDIX

7.1 MEASURED NH_3, NO_2^- AND NO_3^- LEVELS

Date	12/20/2018	12/21/2018	12/22/2018	12/23/2018	12/24/2018	12/25/2018	12/26/2018	12/27/2018	12/28/2018	12/29/2018
NH_3 /NH_4^+ (PPM)	0	0	3	5	5	6	7	7	3	4
NO_2^- (PPM)	0	0	0	0	0	0	1	2	0.5	2
NO_3^- (PPM)	0	0	0	0	0	0	0	0	0	0

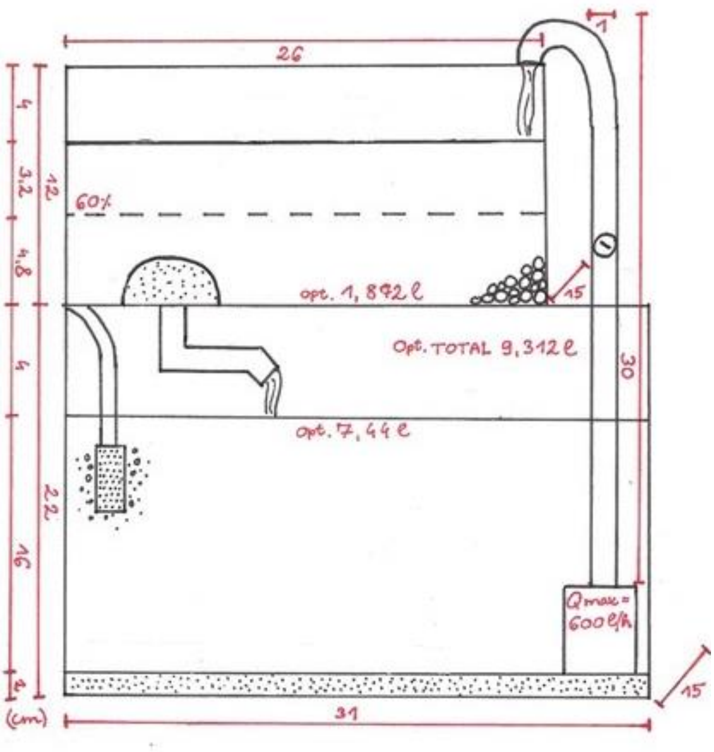
Date	12/30/2018	12/31/2018	01/01/2019	01/02/2019	01/03/2019	01/04/2019	01/05/2019	01/06/2019	01/07/2019	01/08/2019
NH_3/NH_4^+ (PPM)	7	6	4	3	2	2	1	1	0	0
NO_2^- (PPM)	3	4	6	8	9	10	10	8	7	6
NO_3^- (PPM)	0	0	0	5	10	25	50	80	100	150

Date	01/09/2019	01/10/2019	01/11/2019	01/12/2019	01/13/2019	01/14/2019	01/15/2019	01/16/2019	01/17/2019	01/18/2019
NH_3/NH_4^+ (PPM)	0	0	0	0	0	0	0	0	0	0
NO_2^- (PPM)	6	5	3	2	0.5	1	0.5	1	1	1
NO_3^- (PPM)	120	100	100	80	70	70	60	70	70	70

7.2. PRODUCED CHIVE

7.3. ROOTED SWEET POTATO

7.4. PLAN OF THE RECIRCULATING EDUCATIONAL SYSTEM



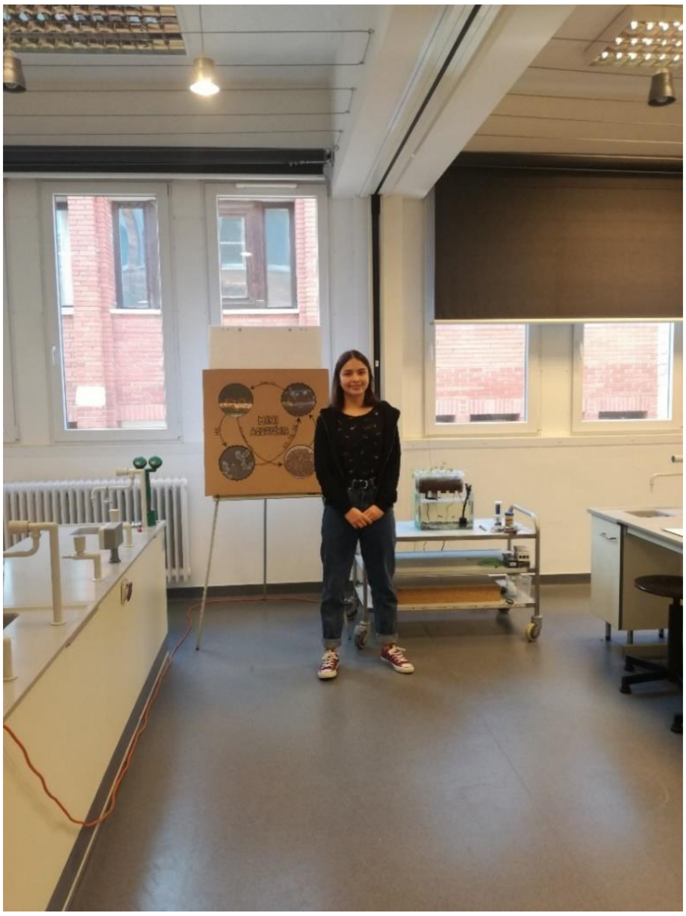
7.5. SUBJECT NO.1

7.6. SUBJECTS NO.2 AND NO.3

7.7. PLANTS IN THE GROW BED

7.8. SEEDS AFTER GERMINATION

7.9. ME AND THE TEACHING MATERIAL



7.10. INTERACTIVE GAME CARDS