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STARTUP STAGES OF A LOW-TECH AQUAPONIC SYSTEM

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Abstract

The goal of the project was to establish a low-tech cheap sustainable food production system that combines traditional fish farming with hydroponics (cultivating plants using mineral nutrient solutions, in water, without soil), in a symbiotic environment. We used local fish and plants species only. The project was conducted in two different stages: "construction" stage and "fish" stage. The goal of the start-up stage was to build the grow bed for the plants, to establish the water circuit, to set the lights and to prepare the fish tank for the fishes. For the "fish" stage we used local fish species (carp and caras). The goal of the stage was to build the nitrogen-fixing bacteria colonies in order to provide a constant NO_3^- rich water (around 50 mg/l), with as low as possible traces of NH_3 / NH_4^+ and NO_2^- (below 0,5 mg/l). This was established by testing the NH_3 / NH_4^+, NO_2^- and NO_3^- values under several environmental changes (pH, temperature, lighting, quantity of fish in the tank etc.) in order to identify the best combinations to achieve the goal. Upon completion of the second stage we'll test different local species of plants with the already established system. The goal of the project is to find the best combinations of fish, plants and environmental conditions in order to have a cheap, sustainable symbiotic food production system, easy to be replicated by anyone.

Keywords: *aquaculture, aquaponics, hydroponics, nitrogen-fixing bacteria, sustainable food systems.*

INTRODUCTION

Nowadays, some of the acute problems humanity must face are related to health and to food security. Unfortunately millions of people currently suffer of hunger. The causes that led to this situation are many and diverse, like world population continuously increasing, local conflicts, over-exploitation of land by intensive agriculture, pollution, climate change effects and so on. Furthermore, the lack of available healthy food combined with poverty leads to diseases, exclusion and social inequality. We seek a solution which will provide healthy food to these communities, making them food-independent, and which will also bring them a steady income on hands. The solution we seek will also need to be able to be implemented in areas with water shortage, degraded soils and under the unpredictable conditions of climate changes as well. As "the first step in a thousand miles journey" such a solution has been identified among the new innovative agriculture technologies: **the aquaponic agriculture**, solution which "ticks" all the requirements mentioned above (Figure 1).

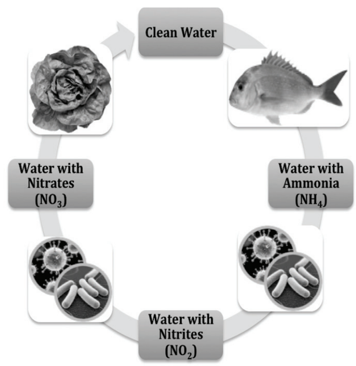

Figure 1. The Aquaponic Solution

The **aquaponic systems** were first described in the early 1980s through the article published by Watten and Busch in 1984 (Connolly and Trebic, 2010). After this first publication interest in aquaponics systems increased and a number of researchers have been working for the development and diversification. One of the most prolific researcher and author of many articles (more than 20 papers) in this field is James Rakocy from University of the Virgin Islands (Rakocy et al., 2006). The most implementations of aquaponic systems are in Australia and America. In Europe the use of aquaponics is scarce. It seems that Italy is among the first European country where attention was given to this food production system.

Aquaponics is a combination of aquaculture and hydroponics for food production that uses nutrient – rich water from fish culture to irrigate and fertilize plants, while the plants clear the water before being re-circulated to the fish tank. Thus this system is a closed – loop system which re-circulates fresh water in which plants and fish grow together symbiotically. In this symbiosis the fish provide most of the plants' needed nutrients and the plans act as bio-filters cleaning the water for fish. Thus the wastes secreted by fish, such as urine and ammonia, are converted by denitrifying bacteria in the hydroponic grow bed into forms readily uptaken by plants for energy and growth (Diver, 2006; Considine, 2007; Nelson, 2008). The most commonly grown species in aquaponic systems are lettuce as plant and tilapia as fish. Systems used for commerce in majority of cases grow tilapia. However, in some systems, experiences have used channel catfish, largemouth bass, crappies, rainbow trout, pacu, common carp, koi carp, goldfish, Asian sea bass (barramundi), Murray cod and ornamental fish. Regarding the cultivated plants the most used are green leafy plants such as lettuce, basil, cilantro, chives, parsley, portulaca and mint. There also have been cultivated tomatoes, cucumbers, cabbage, kale, celery, eggplant and okra but the income obtained from the herbs is much higher and therefore those are preferred (Rakocy et al., 2006; Connolly and Trebic, 2010).

MATERIALS, TOOLS AND METHODS

In achieving its purpose the project is oriented to search the most viable combinations of local plants and fish combinations for real local conditions and to research and deliver blueprints and practical solutions to build customized aquaponics systems, adapted to the climate conditions in Romania, for micro-farms and backyards, in both rural and urban scenarios.

In this respect, the summary of the **main activities** of the project includes:

– to develop aquaponic systems solutions for temperate climate for domestic use (in both urban and rural deployments);
– to chose the appropriate local plant and fish species for the established aquaponic systems;
– to provide adequate seminars accompanied by demonstrations on field, workshops and guidelines on aquaponic agriculture to farmers in disadvantaged areas;
– to advice the future aquaponic systems users how to capitalize further on by emphasizing that the aquaponic systems can be an independent source of steady income and even a provider for new jobs in the community.

After its finalization, the project is expected to trigger a positive impact on the awareness of general public that it is really easy to use modern technologies that can offer healthy food and an extra income.

The system was build out of easy to be acquired, common (even recycled) materials. The main consideration was that the system would be **cheap**, **accessible** and **easy to be reproduced** by anyone (Table 1).

Table 1. List of materials

Materials	Retail Value per Unit (lei)	Nr. of Units
Fish Tank	100	1
Flower Stand	10	1
Water Pump	60	1
Water Heter	65	1
Water Filter	130	1
Fluorescent Lamp	30	1
Timed Power Supply	20	2
Floating Bio Balls	0,5	100
Plastic Tubing	1	1 m
Hydroton	35	10 l

The fish tank was provided for the project by the University. However, the two halfs of a 400 litre plastic barrel (around 100 lei retail value) could have be used instead.

The total cost of the build materials was around 400 lei.

The only **tool** used for the build was a pointed knife, used to cut the plastic tubing and to pierce the flower stand.

To assess the water parameters, the following were used (Table 2):

Table 2. List of water assesment tools

Water Assessment Tools	Retail Value per Unit (lei)	Nr. of Units
Dropper	4	1
Thermometer	17	1
Consumables		
pH Minus	30	1
pH Plus	30	1
Nitrite Removal	25	1
pH Test Kit	40	1
NH_3/NH_4^+ Test Kit	40	1
NO_2^- Test Kit	40	1
NO_3^- Test Kit	40	1

The total cost of the test kits was less than 200 lei. The kits used were titration-type kits, which require the user to take a sample of water from the tank and slowly drip a reagent into the vial to produce a colour end point to be compared against a specific colour-code scale.

The following **methodology** was used to acquire water parameters:

- all test kits were produced by the same company (Sera GmbH). Moreover, all of them belong to the same class of products;
- all tests were conducted in the same conditions of lighting. The pictures were taken with the same camera and under the same conditions (light, angle, flash, hour of the day). The maximum interval between measurements was 2 days;
- the fishes were always feeded only upon completion of the tests;
- the pictures were not edited and were labelled with the date when were aquired.

For the build, the following steps were taken:

- the fish tank was cleaned up and cleansed, then it was filled with regular tap water (around 400 litres);
- in order to reduce Chlorine the water was allowed to sit a few days. The test used was the *smell test*: if one can smell the water, then he water need to be allowed to sit longer;
- the fish tank was then populated with a few small fishes (fingerlings) of different species, (carp, caras and one xifo, on total weight of 50 g) in order for the ammonia/ammonium to build up and the bacteria cultures to start colonize. This process is called "***system cycling***". Toward this purpose, ***Bio Balls*** were added to the system;
- **after two weeks** the flower stand and the water pump were added to the system. The pump was set to continuously circulate the water between the fish tank and the flower stand ("*continuous flow*" timing scheme);
- the solution for the water to return from the flower stand to the fish tank was accomplished by setting up a small waterfall, instead of using the classical pump system. This solution was chosen in order to achieve both water aeration and a constant water stream in the fish tank. Besides that, another water pump was not needed to be added to the system.

Bio Balls is a special designed growth medium for bacteria colonies. The Bio Balls can be placed inside the water filter (for the anaerobic or photophobic bacteria, like *Nitrosomonas*), or can be let float and tumble along with the water current (for the aerobic bacteria, like *Nitrobacter*). This way the waterflow bring more nitrites to the bacteria and, by drifting on the water surface, the necessary Oxygen is also provided to them.

- Hydroton (an expanded clay aggregate with honeycomb core) was used to establish the grow bed;
- a few flower seeds and seedlings were planted. While the seeds were placed on a wool bedding to prevent to be washed out by the stream, the seedlings were placed into small plastic mesh potts (0,5 lei a piece) and secured with hydrotone.
- retail market price for hydroton (10 liters) is 35 lei.

The Tests

The water was sampled and probed during a period of 32 days, between 2013, December 18th and 2014, January 18th. The results are shown in the table below. Later on, detailed graphs will be also provided, in order to relate the measured values for water quality to the activities that took place during the project (Table 3).

Table 3. Water's chemical characteristics and temperature during the test period

Day Nr.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*
NH_3/NH_4^+ (mg/l)	0,2	0,2	0,2	0,2	0,3	0,3	0,6	0,5	0,5	0,5	0,5	0,4	0,4	0,4	0,4	0,4	0,3	0,3	0,2	0,2	0,2	0,4	0,4	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
NO_2^- (mg/l)	0,7	0,7	0,7	0,7	0,3	0,4	3,5	4,0	3,0	2,7	1,8	0,9	0,9	0,9	1,0	0,8	0,6	0,5	0,3	0,2	0,2	0,7	0,7	0,6	0,6	0,6	0,5	0,5	0,4	0,3	0,2	0,2
NO_3^- (mg/l)	30	30	30	30	25	20	30	40	40	45	45	40	45	45	45	45	45	45	40	40	40	40	40	40	45	45	45	45	50	50	50	50
pH	7,8	7,8	7,8	7,8	7,6	7,5	7,4	7,3	7,4	7,4	7,4	7,4	7,4	7,3	7,3	7,4	7,4	7,4	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,2	7,2	7,2	7,2
Temperature (^OC)	22	22	22	22	22	22	22	22	21	21	20	20	19	19	24	25	25	24	23	22	22	22	22	22	22	22	22	22	22	22	22	22

System Cycling

Cycling started when fishes first added ammonia (NH_3) in the water as a product of their respiratory and digestive processes. The uneaten fish food, while decomposing, also provides ammonia in the water. In the water ammonia (NH_3) continuously shifts to ammonium (NH_4^+) and then the ammonium shifts back to ammonia, each one's concentration being related to water's temperature and to pH level (more NH_3 at higher temperatures and pH values). Because ammonia is very toxic to fish (while ammonium is relatively harmless to it), relatively low temperature and pH values are to be preferred. Another factor related to water temperature is to be taken into consideration also: the effect of water temperature on bacteria cultures. Studies show that the optimal temperature for their growth is between 25 and 30 ^OC, while at 18 ^OC the growth rate decreases by 50% and at 10 ^OC by 75%. Around 0 ^OC the bacteria population dies. After taking all above into consideration, a convenient temperature of 22 ^OC was chosen.

Water Temperature

Regarding the temperature evolutions, during the survey some temperature variations have occurred due to equipment failure. First, the water heater has stopped working, which leaded to water temperatures towards 19 ^OC. Afterwards, after a "successful" fix at the pet shop, the water heater refused to stop at the predetermined temperature and the temperature reached 25 ^OC. To conclude, the water heater was finally replaced, and the temperature finally has stabilized to its designated value (Figure 2).

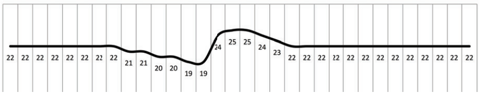

Figure 2. Temperature evolution during the test period

The water heater used was a 300 W Hot 2005 model, with a retail value of 63,99 lei. We weren't able to identify measurable effects of water cooling than heating, except for a adverse reaction (signs of stress) of the flowers when the water was above 23 ^OC.

pH

Generally known as "power of hydrogen", pH measure the ratio between hydrogen (H^+) and hydroxil (OH^-) ions in the water, on a scale between 0 and 14 (value of 7 being known as "neutral"). A higher level of hydrogen ions makes the water "acid", with a pH value between 0 and 7, while a higher level of hydroxil ions makes the water alkaline, with a pH value above 7. To establish a successful aquaponic system a proper pH value of water is critical to be identified and kept at all times for all system inhabitants: fish, plants and bacteria. Toward this purpose, the following are to be taken into consideration:

- Fish have an internal pH value of 7,4;
- Bacteria can operate between 6,5 to 8 pH values;
- Plants are on the "acid" part of the scale, around 6.5 value;
- Nitrification processes tend to lower the value of pH (due to the constant release of hydrogen ions in water)

On our system the pH started at a value of 7,8, dropped toward the 7,5 pH value after bacteria colonies were established, with a continuous lowering trend toward the value of 7,2 during the survey period (Figure 3).

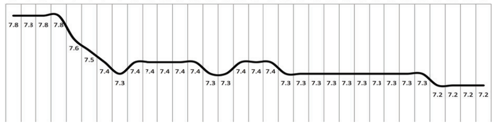

Figure 3. pH evolution during the test period

The "Good" Bacteria

Establishing an aquaponic systems have nothing to do with plants or with fish. Instead, it is all about "growing" bacteria. Not any bacteria, but the so-called "nitrifying" bacteria: ***Nitrosomonas*** and ***Nitrobacter***, the engine of any aquaponic system. They are special because they perform those chemical reactions in the water which make it usable for the plants, and harmless for the fish. To build their own cells they need elements present in the water (oxigen, nitrogen, phosphorus, carbon, potassium and calcium). To be able to use this elements and to run their own metabolism processes, they need energy. In order to get that energy, they drive chemical reactions that release energy. Some of these reactions are the conversion of ammonia to nitrites (NH_3 to NO_2^-) or the nitrites to nitrates (NO_2^- to NO_3^-). The reason for these chemical reactions is not that the bacteria "like" better the nitrogen in nitrites than the nitrogen in ammonia, or that bacteria cares about the welfare of our fishes or plants. The reason is the release of energy that follows the chemical reactions (for example, when the hydrogen ions are replaced by the oxygen atoms).

The first bacteria, ***Nitrosomonas***, is lured by the nitrogen found in ammonia or in other organic amines and, if finds plenty of it, will populate the system. As a result of its action, the ammonia is converted to nitrites (NO_2^-) which, at this stage, worsen the situation for the fish: the nitrites are even more toxic to fish than ammonia. Moreover, because the plants can't feed on the nitrogen found in ammonia or in nitrites, the water becomes even most poisonous for the fish. Fortunately, the nitrites attracts the real "good" bacteria, ***Nitrobacter***, which converts the nitrites to nitrates (NO_3^-). Nitrates are not only harmless for fish but also an excellent source of food for plants. The process of biological oxidation from ammonia to nitrates performed by autotrophic bacteria in the presence of O_2 is known as **nitrification**.

Nitrification Process:

Nitrosomonas:

$2\ NH_3 + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 2\ H^+$

Nitrobacter:

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

At this point, the water in a successful implementation of an aquaponic system will show:

- as little as possible (less than 0,5 mg/l) ammonia / ammonium: *it means that* ***Nitrosomonas*** *feeds on almost all ammonia / ammonium available*;
- traces of nitrates: *it shows that* ***Nitrobacter*** *colonies are established*;
- as little as possible (less than 0,5 mg/l) nitrites - ***Nitrobacter*** *feeds on almost all nitrates available*;
- a slow yet constant drop of pH value, due to the release of hydrogen ions in water as a byproduct of nitrification process.

How the amount of nitrates (NO_3^-) in water help to *asses* an aquaponic system

The amount of nitrates in the water gives value information regarding the equilibrium of the system:

– if the nitrates are very close (but not equal) to 0 mg/l, it means that the system is in equilibrium (no fish or plants are needed to be added or removed) - **the best scenario**;

– if the nitrates are high, it means that more plants have to be added to the system;

– if the nitrates are equal to 0 mg/l, it means:

- if the nitrites are at normal values (close to zero), the plants need more nitrates than the available amount provided by the bacteria (*more fish have to be added to the system, or some of the plants have to be harvested*);
- if the ammonia and / or the nitrites are also high, the bacteria cultures are probably dead (*countermeasures are to be taken, or the fish will die. In this case further research is needed to find out what happened. Based of the conclusions of the research the appropriate measures should be taken to stabilize the system further more)*

The System

In the end, a final configuration was chosen and the start-up stages of the aquaponic system were successfully completed (Figure 4). <u>No fish was lost during the setup process</u>.

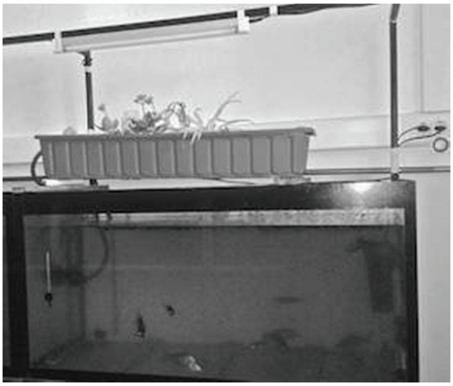

Figure 4. The assessed aquaponic system

RESULTS AND DISCUSSIONS

A correlation may arise between the events which had happened and the values for the measured water quality parameters, easy to be identified on the timeline of this stage of the project (Figure 5).

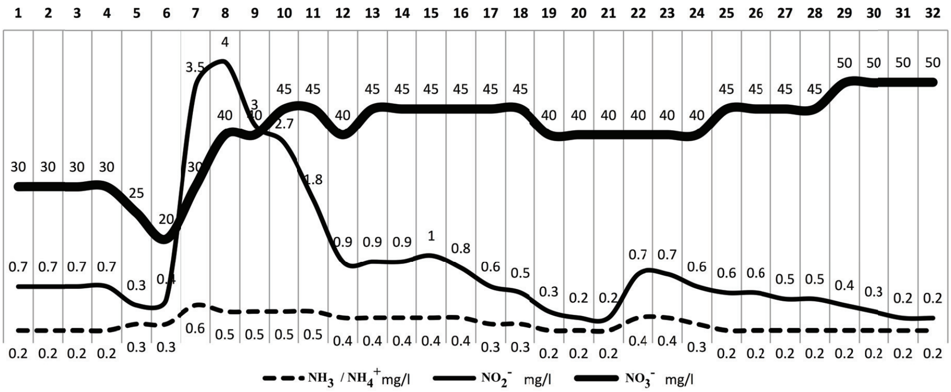

Figure 5. The dynamics of NH_3 / NH_4^+, NO_2^- and NO_3^- concentrations during the test period

- on December 20th - the flower stand and the water pump were added to the system. The pump was set to "*continuous flow*" timing scheme.
- on December 21st - the pump was set to "*flood & drain*" timing scheme (15 min "on" / 30 min "off"). The grow bed was established, and three flower seedlings were placed in plastic mesh pots and secured with hydrotone. The juice from a lime (pH 6,4) was added to lower the pH value.

Discussed results: NO_3^- decreased from 30 mg/l to 20 mg/l between December 21st and 23rd;

Explanation: the seedlings started to feed on NO_3^-;

Discussed results: NH_3 value increased from 0,2 mg/l to 0,3 mg/l, while NO_2^- value decreased from 0,7 mg/l to 0,3 mg/l. The variations on both parameters were around the same margin (50%);

Explanation: the Citric Acid ($C_6H_8O_7$) in lime juice killed some of the ***Nitrosomonas*** *colonies (responsable to reduce the quantity of NH_3 while providing NO_2^- instead);*

Discussed results: pH value decreased from 7,8 to 7,5

Explanation: Lime juice effect.

- on December 23rd - a new 500 g batch of fishlings was added to the system;

Discussed results: NH_3 value increased from 0,3 mg/l to 0,6 mg/l (on Dec 24th).

Explanation: The new fishes in the system added to the NH_3 level.

Then, on December 25th, **NO_2^- value suddenly jumped from 0,3 mg/l to 3,5 mg/l and soon reached the 4,0 mg/l mark**;

Explanation: NO_2^- value skyrocketed because a very small amount of ***Nitrobacter*** *colonies were left in the system to break NO_2^-, probably as a late effect of the lime juice.* This situation called for rapid countermeasures, otherwise the fish population could have been lost.

– on December 25th- JBL Denitrol was added to the system, and the NO_2^- value rapidly started to decrease from 4,0 mg/l to 1,0 mg/l (on Dec 29th).

Discussed results: Between December 29th and January 7th, the amounts of NH_3 and NO_2^- decreased steadily, under almost the same gradients;

Explanation: Both bacterial cultures have adapted to the new fish population.

– January 7th: a new 300 g batch of fishlings was added to the system;

Discussed results: increased values of NH_3 and NO_2^- were measured on January 8th and 9th. Afterwards, a steady decrease of NH_3 and NO_2^- values occurred, again, both under a very similar gradient;

Explanation: The bacteria cultures compensated the new conditions;

Other events have had occurred during the project, but apparently they did not caused any measurable changes to water quality parameters:

– December 25th - decrease of pump waterflow;
– December 27th - increase of pump waterflow;
– December 29th - a timed lighting system was added to the system (lights "on" between 6 a.m. and 9 p.m.);
– January 7th - the "flood & drain" timing scheme was altered to 30 min "on" / 30 min "off".

CONCLUSIONS

An aquaponic system is an easy to build system for anyone with some basic practical skills. No special tools or skills are required in the process.

The cost of such a system may vary with the type of the materials used and the scale of the project, but one can setup a basic system for as low as 100 euro.

Labor wise, the system needs more attention during its cycling, when you have to run all the tests on daily bases. However, sampling and testing the water will not require more than one hour per day. Afterwards, on a balanced running system, the tests should be run no more than once a week.

Spare parts are not mandatory, but it is recommended to have some spares always on hand (the water pump is the most obvious one). A spare power source may also be a recommended acquisition, along with a set of "first aid" tools (pH Plus, pH Minus, Denitrol etc.) to be used in case of emergency.

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