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SYSTEM CYCLING STAGE ON AQUAPONIC SYSTEMS AS REQUIRED PREREQUISITE FOR SOILLESS AGRICULTURE

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Abstract

The goal of the project was to establish a self-sustaining herb production unit in a soilless environment, using an aquaponic system as a bionutrient source for the plants.
Aquaponic systems are closed-loop symbiotic systems of aquaculture and soilless agriculture which uses nutrient-rich water from the fish culture to irrigate and fertilize the plants, while the plants clear the water before being recirculate to the fish tank. In this process, the wastes generated by the fish (such as urine, ammonia and decomposed fish fodder) are converted by nitrifying bacteria into forms readily to be assimilated by plants. The process of building the nitrifying bacteria cultures is known as "cycling". On this process the daily values of temperature, nitrates, nitrites, ammonia and pH in the fish tank water are to be assessed and controlled toward the goal of having the bacteria cultures established as quick as possible. The methodology of choice for the assessment of nitrates, nitrites and ammonia was spectrophotometric determination.
After completion of cycling stage, a soilless grow bed for the plants was established. Different combinations of substrates and plants are to be tested on this stage of the project, in order to achieve the best combination of "pairs" of substrates and plants to be grown in an aquaponic setup.

Key words: *aquaponics, nitrification, nitrogen-fixing bacteria, spectrophotometric determination.*

INTRODUCTION

Worldwide, in our days millions of people are facing hunger. They are also affected by food security issues (FAO, IFAD and WFP, 2013). The causes may be diverse: rapid population growth (practically the global population has doubled in the last 50 years), local conflicts, over-exploitation of lands, pollution and so on. One of the ways to solve food security issues is the use of *aquaponics systems*, the combined culture of plants and fish in symbiotic systems in which fish wastes provide nutrition to the plants, which, in turn, purify the water for the fish (Diver, 2006). Basically, water is continuously recycled among the fish tanks to the plant grow beds, and then back to the fish tanks. This recirculation capitalizes on the mutually beneficial (symbiotic) relationships among three components: fish, beneficial bacteria, and plants (he most commonly species grown in aquaponics systems are lettuce as plant and tilapia as fish). So, fish are raised on healthy vegetarian feed, bacteria convert fish waste and non-eaten fish fodder into nutrients necessary for plants growth, while the plants serve as a biofilter, purifying the water before it is returned to the fish tanks (Rakocy et al., 2006; Pantanella, 2010) (Figure 1).

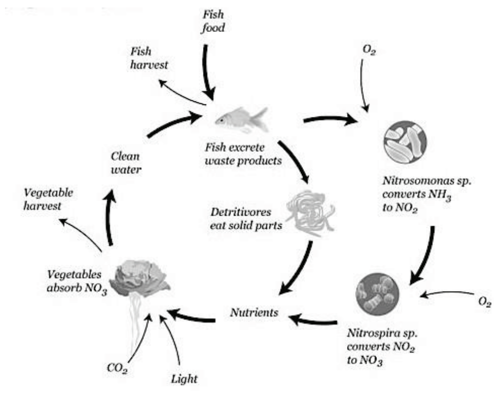

Figure 1. How aquaponic systems works

However, establishing a successful aquaponic systems is all about "growing" the "good bacteria" that perform those chemical reactions in the water to transform the compounds which are harmful for the fish and not usable by the plants into compounds harmless for the fish and usable for the plants, process known as "nitrification" (part of the global nitrogen cycle). The process of luring and establishing of "good" bacteria colonies is known as "system cycling".

In this context, the paper presents the cycling stage of an aquaponic system built out of a newly built non-cycled ornamental aquarium.

MATERIALS AND METHODS

In order to transform the new aquarium into an aquaponic system the following steps were taken (Elia et al., 2014; Connolly and Trebic, 2010):

- a grow bed was set up aside the fish tank and on top of a water collector tank;
- the grow bed was then provided with an overflow system in order to guide the excess water into the water collector tank;
- a layer of gravel on top of a layer of hydrotone was used as grow media;
- a lightning system was set up above the grow bed to provide light and heat to the plants;
- a piping system was set up between the fish tank and the grow bed, and between the collector tank back to the fish tank;
- a new biofilter was added to the system as a replacement for the power filter found in the aquarium;
- two water pumps controlled by an automatic "smart" control unit were added to the system;
- basil and parsley seedlings (grown from seeds aside the system) were used in the cycling stage.

In this build the water is recirculated in a closed loop from the aquarium and through the filter to the grow bed, and from the grow bed, back to the aquarium through the water collector tank (Figure 2).

Figure 2. The aquaponic system

The cycling stage of the system took place between December 2014 - January 2015. During that period water temperature, pH value and nitrogen concentration (NH_3/NH_4^+, NO_2^-, NO_3^-) were daily assessed (Hodoșan, 2012; Hodoșan, 2014). While water temperature and pH value were determined by direct observation (using a thermometer and a commercial test kit), nitrogen concentrations were determined by using spectrophotometric analysis of water probes (Hodoșan, 2014). This method requires measuring the intensity of light as a beam of light passes through the probe, knowing that each chemical compound absorbs or transmits light over a specific and known wavelength. The concentration values of nitrites and nitrates are then determined from the benchmark curves built out of the extinctions shown by spectrophotometer.

RESULTS AND DISCUSSIONS

The main sources of organic nitrogen in the water are fish and plants. Since an aquaponic system will not have aquatic plants planted in the fish tank the organic ammonia will mainly be the result of fish's respiratory and digestive systems activities and from decomposed fodder (Nicolae, 2007). An important step in the global nitrogen cycle starts when ammonia is oxidized to nitrates under the action of autotrophic bacteria, process known as "nitrification". Further, the final phase of nitrogen cycle take place, when nitrates are oxidized back to nitrogen by heterotrophic bacteria, process known as "denitrification". In context, autotrophic bacteria metabolize carbon out of CO_2 molecules, while heterotrophic bacteria metabolize carbon out of organic carbon compounds.

The process of interest in aquaculture systems is nitrification.

In the water ammonia is found at all times in both ionized and non-ionized forms, (ammonium and ammonia), the ratio between the two forms being related to water's temperature and pH level (more ammonia at higher temperatures and pH values).

$$NH_3 + H_2O <=> NH_4^+ + HO^-$$

Because ammonium is less toxic to fish than ammonia, relatively low temperature and pH values are to be preferred if possible. The sum of the two forms of ammonia (ionized and non-ionized) represents *Total Ammonia Nitrogen* (*TAN*). In the aquaculture systems the level of ammonia is empirically calculated based on the quantity of fish fodder (1 kg of fish fodder delivered to the fish ultimately produce 30 grams of ammonia). In our new system, right after the fish were added to the fish tank, ammonia started to build up. This stage represent both the beginning of System cycling and of nitrification process. Once ammonia was present in the system, the first colonies of nitrifying bacteria *Nitrosomonas* started to be established. Nitrosomonas, in order to build their own cells, need to gather elements present in the water (oxygen, nitrogen, phosphorus, carbon, potassium and calcium). To be able to use these elements and to run their own metabolism processes, they need energy. In order to get that energy, they drive chemical reactions that release energy as follows:

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

or

$$2\ NH_4^+ + 3\ O_2 => 4\ H^+ + 2\ NO_2^- + 2\ H_2O$$

This process converts ammonia into *nitrites* (NO_2^-), a compound even more toxic for the fish than ammonia (NH_3). *This point is the critical point of cycling. If not managed well, all fish can die as a result of the presence of both NH_3 and NO_2^- in the water*. Lured by the presence of NO_2^- in the water, the second nitrifying bacteria (*Nitrobacter*) start to colonize the system. Nitrobacter converts the nitrites to nitrates (NO_3^-), a nitrogen based compound *harmless to fish and an excellent food supply for plants*, as follows:

$$NO_2^- + 1/2\ O_2 => NO_3^-$$

Considering both stages of system cycling as phases of a unique process, the total reaction of nitrifying bacteria is (Gujer and Boller, 1986):

$$NH_4^+ + 2\ HCO_3 + 1{,}9\ O_2 =>$$
$$=> NO_3^- + 2{,}9\ H_2O + 1{,}9\ CO_2 + 0{,}1\ CH_2O$$

where CH_2O is cellular biomass.

We can now assess that 1 g of NH_3 consumes during the nitrification process 4,34 g O_2 and 7,14 g alkalinity in order to produce 0,21 g cellular biomass and 4,43 g nitrates.

The nitrification process depends on ammonia level, pH value, alkalinity, temperature, solvate oxygen and light:

- any level above 2 mg/l of NH_3 stops nitrification;
- any value of pH between 6 and 9 is optimal for the nitrification, faster around value of 9 and slower around 6. Though, around the high values of pH, the ratio between ammonia and ammonium will favor ammonia, which is harmful to fish;
- alkalinity is a limiting factor also, since it is consumed during the process;
- there is no nitrification process above 38 ^OC and below - 5^OC

The nitrification process and can be identified by assessing the values of water parameters obtained during system cycling (Figure 3):

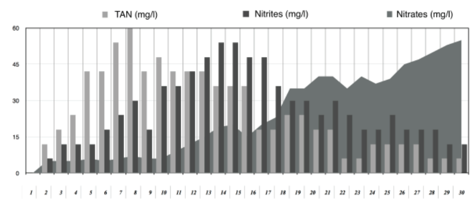

Figure 3. TAN, NO_2^- and NO_3^- values during system cycling

The daily outcome of the project was:

- day no. 1 - some random fishes were added to the system in order to provide ammonia;
- day no. 7 - NH_3 - 1 mg/l; NO_2^- - 0,5 mg/l; NO_3^- - 0,15 mg/l. Conclusion: Nitrosomonas started to colonize the system;
- day no. 7 - 50 litres of water were removed from the aquarium and replaced with 50 litres of nitrogen-free water;
- day no. 14 - NH_3 - 0,6 mg/l; NO_2^- - 0,8 mg/l; NO_3^- - 20 mg/l. Conclusion: Nitrosomonas colonies are established. Nitrobacter started to colonize the system;
- day no. 14 - 50 litres of water were removed from the aquarium and replaced with 50 litres of nitrogen-free water;
- day no. 25 - system cycling was concluded. The levels of NH_3 and NO_2^- dropped below 0,2 mg/l, with NO_3^- in excess of 40 mg/l. *The system is ready to receive fish and plants in order to start production.*

CONCLUSIONS

Food security poses a very real and serious threat in the world today. What makes aquaponic food production so attractive is its ability to address these issues of resource conservation and access to a reliable and quality food source (Mc Murtry et al., 1990). In addition to this, the simplicity of an aquaponic system makes it accessible and friendly use so it has the potential to help families who are most in need of it. The addition of some income through in the form of food has the ability to significantly impact the lives of families (Nelson, 2008). Furthermore, it can be a profitable endeavor and a lucrative vegetable and fish production for farmer or family that developed an aquaponic system. The potential is high for this type of agriculture and it will likely gain notoriety as global circumstances continue to necessitate an increasing amount of innovation, conservation, and consciousness.

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