AQUAVET

INTRODUCING AQUAPONIC IN VET:
TOOLS, TEACHING UNITS AND TEACHER TI

Result 2:

Description of the aquaponic system

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Contents

1 Description of the result

This result gives an introduction to aquaponics, what it is, the different ways in which it can be built and operated, as well as important parameters of the system.

After a short definition of what aquaponics is, chapter 3 describes the common elements of an aquaponic system and presents a possible arrangement for one such system. Building on the possibility to construct various systems, two different operational modes are depicted. One where there is integrated sludge usage and the other with sludge separation. Furthermore an experimental system built in Slovenia is introduced, as is the use of floating treatment wetlands in aquaponics, which concludes chapter 3.

Chapter 4 consists of a table listing essential parameters of the aquaponic system. Those parameters are used to assess the functionality and health of the system on a regular basis. A short explanation to each parameter is given.

Not only can the aquaponic system as a whole be constructed in different ways, but also the crop production system. Chapter 5 names three different crop production methods, before figure 6 shows all possible soilless cultivation systems. The advantages and disadvantages of soilless cultivation are explicated after which details about some of the cultivation systems listed in figure 6 are presented.

The last chapter lists potential fish and crops that can be cultivated in aquaponic systems. For the potential fish advantages and disadvantages are named. The list of crops is based on the various types used in research or experiments on aquaponics.

Annex includes two papers produced for the dissemination during the project AQUA-VET. One is about Multifunctional aquaponic systems used as research and training lab, the other about the implementation of Aquaponic in classrooms as a tool to promote system thinking.

2 What is Aquaponics?

Aquaponics is a polyculture consisting of aquaculture (a fish-farm) and hydroponic (plants, which are cultivated in the recirculation water of the fish tanks). The primary goal is to reuse the nutrients contained in fish feed and fish faeces to grow crop plants. (Graber & Junge 2009: 148-149, Rakocy et al. 2003: 63, Lennard & Leonard 2006: 539-540) Aquaponics is a cleaner production technology: it uses effluent and sludge from fish production in an integrated vegetable/fruit production system to make use of these residual nutrients. Fish excrement can either be used as nutrients by plants directly or after bacteria convert ammonia to nitrite and nitrate. (Rakocy 2012: 343) The fish feed adds a continuous supply of nutrients to plants solving the need for any discharge and replacement of depleted nutrient solutions or the adjustment of the solutions as in hydroponics. Without having to buy additional fertiliser for the plant crop the profit potential of the system increases. (Rakocy 2006: 2) Possible benefits of aquaponics are (Diver 2006: 4; The Aquaponics Doctors 2012):

- Conservation of water resources and plant nutrients
- Efficient use of one nutrient source (fish feed)
- No use of chemical herbicides or pesticides
- Reduced operating costs (compared to aquaculture or hydroponics)

In addition, aquaponic systems require less water quality monitoring than separate hydroponic or recirculating aquaculture systems and require less land than ponds and gardens. (Rakocy 2006: 2) Aquaponics is thought to become a future production method for locally grown food, e.g. in an urban environment with smaller production units designed for homes and restaurants. It can be operated in different climates and anywhere and can increase the productivity of the available space. (Karlsdottir et al. 2012: 3)

3 Overview of the aquaponic system

There are a lot of ways to actually design an aquaponic system. In the end it should fit with the intended production goals. R3 will go into more detail concerning the operation of the system that was built. This paragraph intends to name the components that can be found in any aquaponic system.

Aquaponics can be viewed as a specific form of recirculating aquaculture systems (RAS). Since aquaponics is a combination of aquaculture of fish and hydroponics of crops, one part of the system is a fish tank, where the fish are reared. The fish are fed and through their metabolism faeces and ammonia are excreted into the water. Left over fish feed also adds nutrients to the water. But high concentrations of ammonia are toxic for fish. Therefore, effluent from the fish tank flows through a filter where suspended solids are removed to reduce the organic matter concentration and prevent clogging of pipes and the plant roots. Through nitrifying bacteria, ammonia is transformed to nitrite and further to nitrate, which is relatively harmless to fish and is the favoured form of nitrogen for growing crops such as vegetables. (Rakocy 2006: 1) This process either happens directly in the hydroponic unit or via a separate biofilter. Both areas provide a surface for biofilm growth (e.g. gravel, sand, expanded clay, biofilter media). The dissolved nutrients (like nitrate) are taken up by the plants. In the end the “treated” water flows into a reservoir or sump from where it is transported back to the fish tank. (Rakocy 2012: 345-346; Graber & Junge 2009: 147-149; Diver 2006: 3) Figure 1 shows a schematic of this. Figure 2 depicts a more detailed possible arrangement of an aquaponic system.

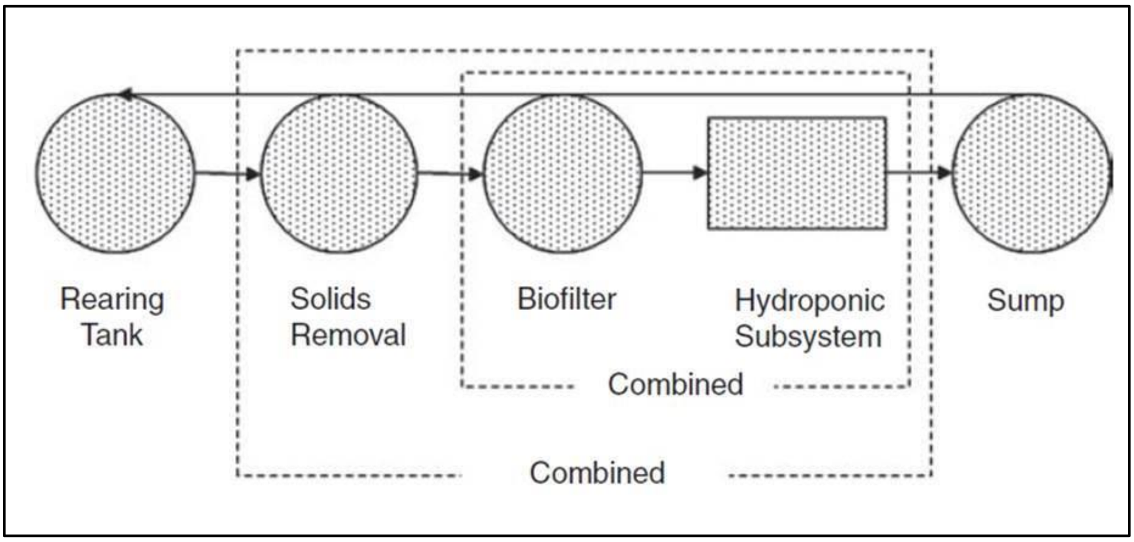


Figure 1: Components of an aquaponic system (Rakocy 2012: 346)

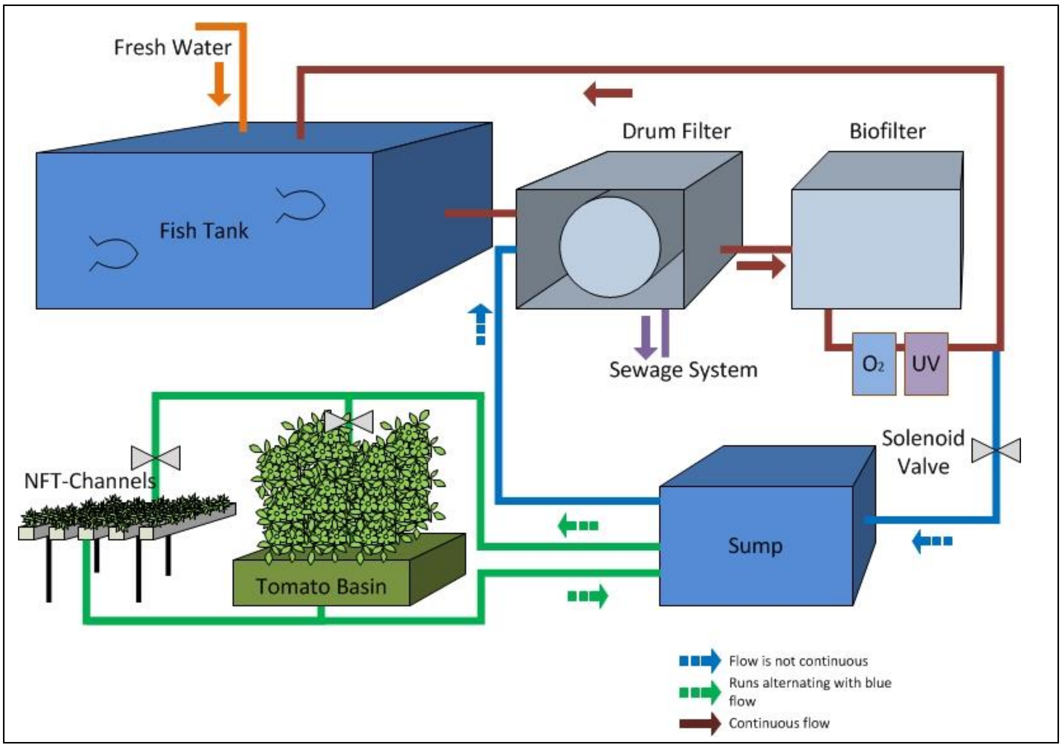


Figure 2: Possible arrangement of an aquaponic system.

From the fish tank the water flows to a drum filter where suspended solids are filtered and discharged. Nitrification takes place in the biofilter, after which oxygen can be added and UV-radiation step can also be included. The circulation between the fish tank and the two filters is continuous. When allowed, the water proceeds to the sump from where it is transported onwards to the crops. It returns to the sump and flows back to the drum filter, where it re-enters the ongoing circulation between fish tank and filters.

The differences mentioned above can also be seen in the operational modes of the system: either with integrated sludge usage or with sludge separation (Figure 3).

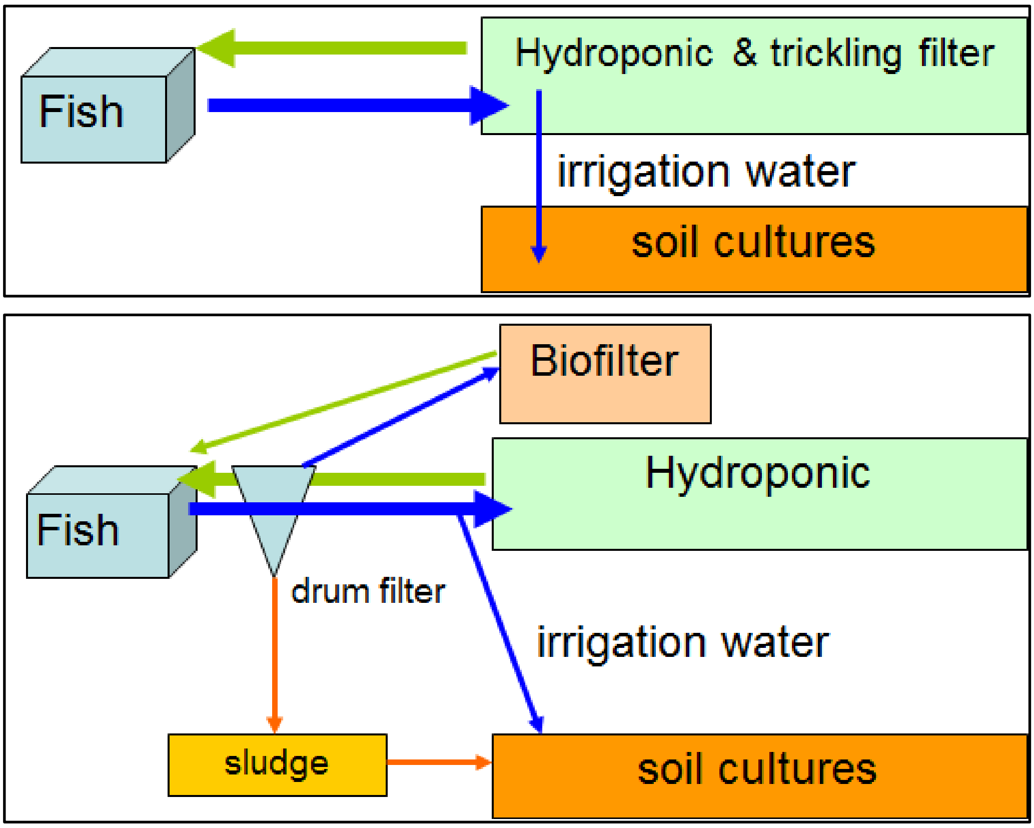


Figure 3. Above: Aquaponic system with integrated sludge usage.
Below: Aquaponic system with sludge separation (Graber 2014).

Each mode has its adavantages and disadvantages. Integrated sludge usage has extensive fish stocking of up to 10 kg/m^3 and there is complete nutrient recycling. But negative aspects include turbid water, and reduced biofilter performance. Sludge separation on the other hand allows intensive fish stocking of up to 50 kg/m^3. Positive aspects are the clear water, lower BOD (biochemical oxygen demand) concentration, lower microbial load and optimized biofilter performance. On the negative side there is only partial nutrient recycling, and additional sludge treatment step (on-site or off-site) such as vermicomposting, is necessary (Graber 2014).

An example of an aquaponic test system can be found within the AQUA-VET project. An experiment was undertaken by Griessler-Bulc et al. (2012) in Slovenia. Their aim was to reduce water pollution in a small-scale cyprinid fish farm by diverting recirculating water into an aquaponic system. This closed-loop system consisted of a treatment train made up of a lamellar settler, roughing filter, vertical constructed wetland planted with tomatoes and an ultrasound device. (Griessler-Bulc et al. 2012: 1-2) The formulated hypothesis was that a system with those parts "[…] can restrain suspended solids as well as dissolved nutrients and counteract algae growth […]". (ibid.: 9) Figures 4a and 4b show the arrangement (4a) and cross section (4b) of the different parts of the test system.

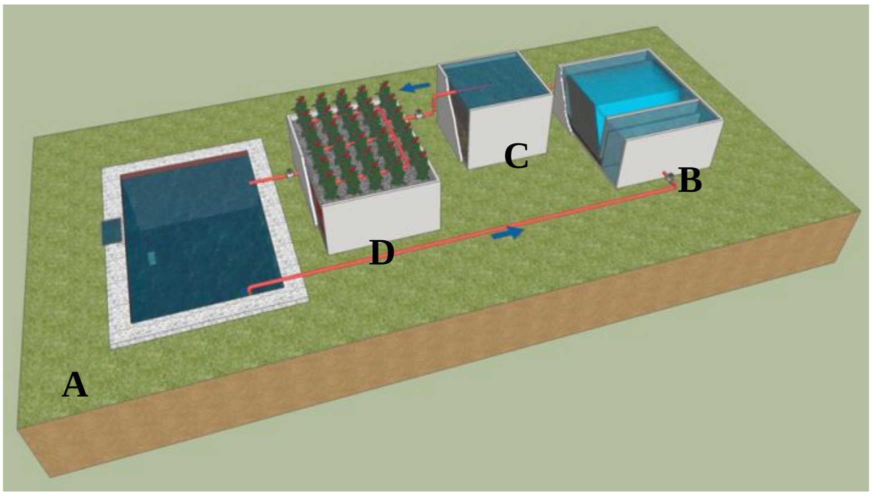


Figure 4a: Arrangement of experimental aquaponic system in Slovenia (Griessler-Bulc et al. 2013)

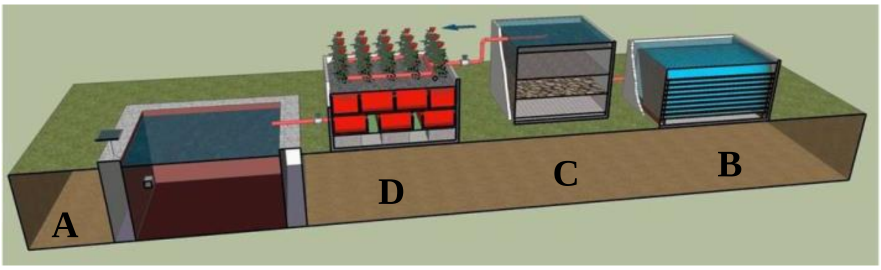


Figure 4b: Cross section of experimental aquaponic system in Slovenia (Griessler-Bulc et al. 2013)

From the fish pond (A) the water flows through the lamellar settler (B) on to the the roughing filter (C) and into the vertical constructed wetland planted with tomatoes (D), from where it returns into the fish tank. In the experimental fish tank, there was an aeration unit and an ultrasound transducer. Next to the experimental pond, there was control pond, which was not part of the recirculating system (ibid.: 2-3). The relevant system parameters (see also Chapter 4) were monitored to assess the system performance. The results revealed that the system efficiently removed total suspended solids, biochemical oxygen demand, chemical oxygen demand, ammonium and total phosphorus, but nitrate and nitrite were removed inefficiently. They concluded that aquaponics can help the aquaculture industry to reduce excessive water demands and chemical use (ibid.: 9). For a more detailed study on using ultrasound on algal control, see Krivograd Klemenčič and Griessler-Bulc (2010).

3.1 Use of floating treatment wetlands in Aquaponic

Another possibility to reduce water pollution is to use floating treatment wetlands (FTW), as shown by De Stefani et al. (2011) and Mietto et al. (2013). The floating phytoremediation can be done using Tech-IA floating elements, which serve as support for plants. The prototype Tech-IA, designed and built by the University of Padova in collaboration with PAN s.r.l., is rectangular (90x50 cm) and weighs about 2 kg (Figure 5). The system is made by recyclable material Ethylene Vinyl Acetate (EVA), has high mechanical resistance, extreme tolerance to chemicals, biological and climate agents and can tolerate loads up to 20 kg. Each element is a closed structure and is equipped with eight windows that allows to sustain the plants and six holes to anchor other elements or the banks

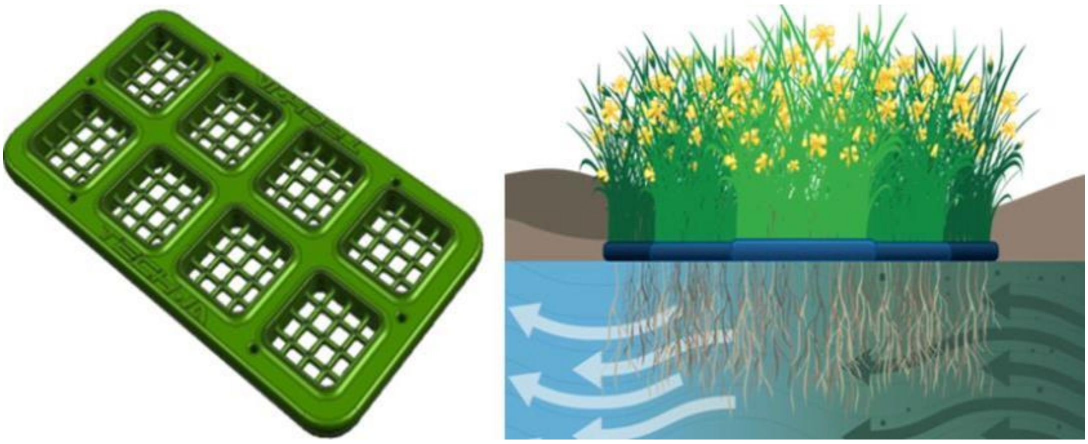


Figure 5: Tech-IA floating element and its usage (PAN 2014).

The floating system enables different macrophyte species to grow on water bodies. They take up dissolved nutrients and the root system supports microorganisms that live in a symbiotic relationship with the plants. (De Stefani et al. 2011: 158). In the context of aquaponic FTWs could also be used as shading for the fish tanks. Previous trials on carp breeding in Italy reported a better water quality and a higher carp growth in the tank with Tech-IA (Figure 6).

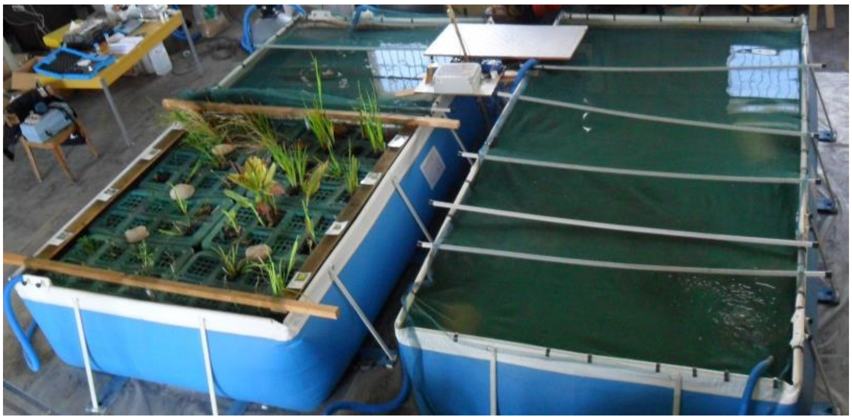


Figure 6: An indoor pilot carp breeding plant with and without Tech-IA inclusion (Florio et al. 2014).

4 Essential parameters of the aquaponic system

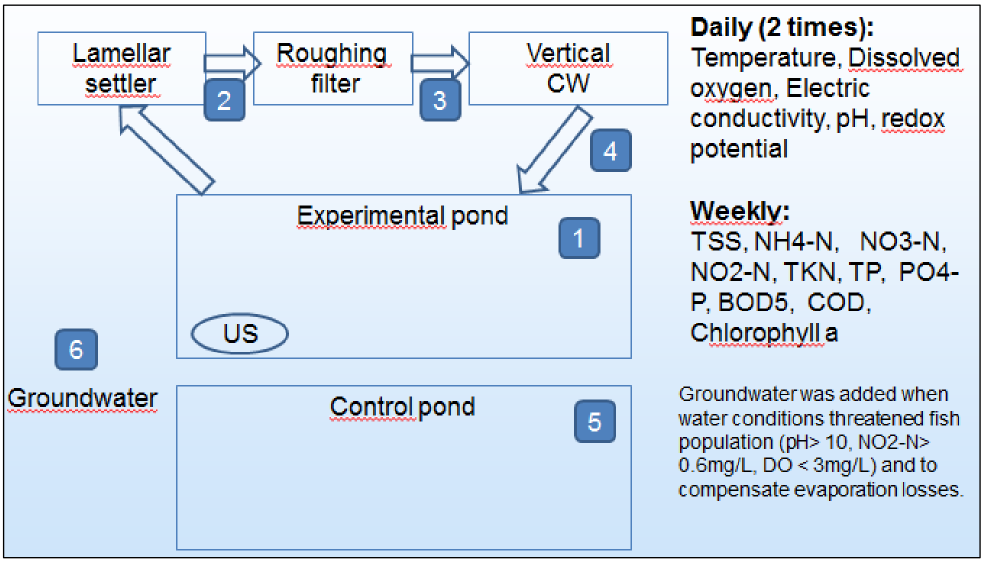
Table 1 lists important parameters that will have to be monitored regularly. The explanation to the parameters should help understand how each of them is of interest.

Table 1: Essential parameters of the aquaponic system

Parameter	**Explanation**
Fish feed fed (g)	Nutrient input for fish and plants
Water level	To ensure proper functioning of pumps
Water replacement	To adjust for evapotranspiration and splash
Air temperature	Influence on water temperature and plant growth
pH	Fish and plants have certain preference and is important for survival
Temperature of tank water	Important for fish survival
Electric conductivity	Indicates the sum of the ion concentration i.e. salinity
Dissolved oxygen (DO)	Important for fish survival
Ammonium NH_4	To make sure the biofilter functions
Nitrite NO_2	To make sure the biofilter functions
Nitrate NO_3	Measure uptake of nutrients
Phosphate PO_4	Measure uptake of nutrients
Potassium K	Needed for plant growth (sometimes in deficit)
Input of calcium hydroxide	To maintain pH at around 7.0, adds calcium for plants
Input of potassium hydroxide	To maintain pH at around 7.0, adds potassium for plants
Light for fish tanks	Preferably little or no light for fish tanks in order to prevent growth of unwanted algae (which might, among others, give an off taste to the fish). Alternatively: tanks covered with planted floating elements.
Light for plants	These need as much light as possible
Fish health	
Plant health	
Biomass growth (fish & crops)	

(Own illustration. information taken from Graber & Junge 2009: 149-154; Lennard & Leonard 2006: 543; Rakocy 2012: 352; Palm et al. 2014: 21; De Stefani et al. 2011: 158; Rakocy 2006: 2-11)

In chapter 3 the Slovene experimental system of Griessler-Bulc et al. (2013) was presented. For that system, they devised a monitoring concept. This concept is drawn up in Figure 5. The parameters that were measured twice daily and those measured weekly on 6 sampling points (marked blue) are listed in the figure.



Daily (2 times): Temperature, Dissolved oxygen, Electric conductivity, pH, redox potential

Weekly: TSS, NH4-N, NO3-N, NO2-N, TKN, TP, PO4-P, BOD5, COD, Chlorophyll a

Groundwater was added when water conditions threatened fish population (pH> 10, NO2-N> 0.6mg/L, DO < 3mg/L) and to compensate evaporation losses.

Figure 7: Monitoring concept for the experimental aquaponic system in Slovenia (Griessler-Bulc et al. 2013).

5 Crop production systems

Rakocy (2012: 373) distinguishes between three production systems for crops: staggered cropping, batch cropping and intercropping. With staggered cropping, plants in different development stages are grown at the same time. Therefore harvesting takes place regularly and nutrients in the water are continuously used. Batch cropping on the other hand means that the entire crop is harvested at the same time and subsequently regrown (Rakocy 2012: 373; Rakocy et al. 2003: 65). Finally, intercropping implies that two or more diverse crops are planted and grown at the same time. Due to different plant and fruit growth rates, nutrient uptake and harvests are spread over some time.

Another possibility is to distinguish between different soilless cultivation forms. Figure 8 gives an overview of the different types.

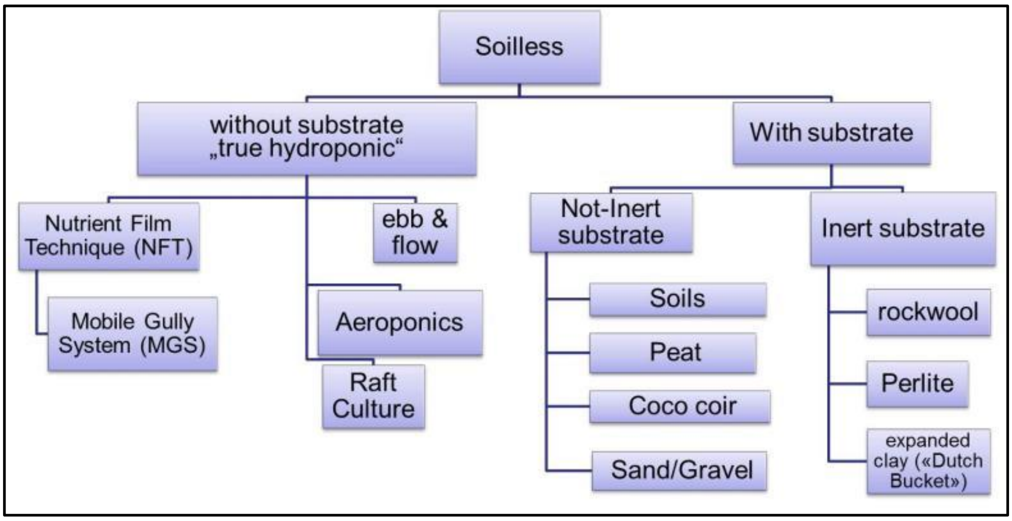


Figure 8: Different types of soilless culture (Junge 2014, Baumann pers. comm.)

Mathis (2014: 15-16) summarises the advantages and disadvantages of soilless cultivation. Advantages include:

> *“conservation of water and nutrients → reducing pollution of land and streams with chemicals that should not get lost; crops can be grown where no suitable soil exists or where soil is contaminated, maybe with plant disease; labor for tilling, cultivating, fumigation, watering and other practices is largely eliminated; maximum yields are possible, making the system economically feasible in high-density and expensive land areas; soilborn plant diseases are eradicated in closed systems and recirculating systems reduce volume of waste waters.”*

On the other hand, there are disadvantages:

> *“construction costs per area are quite high; well trained personnel is needed. High requirement on knowledge in plant nutrition and plant growth; soilborn diseases and nematodes may spread quickly to all beds of the same nutrient tank in a closed system; plant varieties adapted to controlled growing conditions require research and development; the reaction of the plant to good or poor nutrition is fast. The grower has to observe the plants every day.”*

Lennard and Leonard (2006) compared three of the soilless sub-systems, which are most commonly used – Gravel bed, floating raft and Nutrient Film Technique (NFT) – in aquaponic systems with Murray cod (*Maccullochella peelii peelii*) and Green Oak lettuce (*Lactuca sativa*). According to the authors, there are certain advantages that come with each sub-system. Sand/gravel can filter solids and can act as a substrate for nitrifying bacteria, which makes a separate biofilter unnecessary. NFT has the advantage of being cheap and easy to construct, as well as having lower weight than the other two options. (Lennard & Leonard 2006: 540) The goal of the study was to find out whether one of these sub-systems was better in nutrient stripping, led to less water consumption as well as better plant yields and fish growth. NFT was identified to be less efficient than gravel bed or floating rafts when looking at nitrogen removal, whereas fish growth was not affected one way or the other. They concluded, that NFT could still be an appropriate choice for an aquaponic system, since it has lower capital costs and is easy to use and construct, as already mentioned above. Nevertheless, the poorer ability to remove nutrients of NFT should be taken into account when designing the system. (ibid.: 547-549)

Mathis (2014: 19-29) gives an overview of different hydroponic and aquaponic production systems and their advantages and disadvantages. Some of these were also tested at the Zurich University of Applied Sciences (ZHAW, P0) in Wädenswil.

Floating system / raft system / deep water flow DWF

The floating raft system is widely used in Hydroponics and Aquaponics. Its simple construction and hydroponic unit are advantages compared to other methods. This system has also got excellent buffering of water and nutrients and there are few production risks. On the other hand, negative aspects include the need for additional oxygen supply, if the water circulation is too slow. Due to organic matter there might be clogging. In addition, there is algal growth if the water surface is not covered completely. Furthermore, the pumps run most of the time and the equipment is expensive. (Mathis 2014: 19-20)

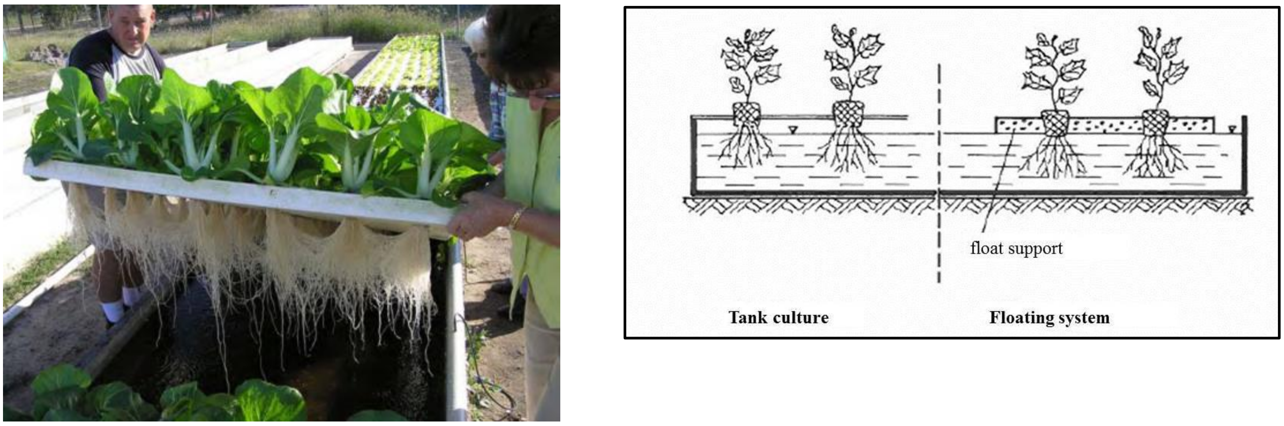


Figure 9: Pak choi rafts (Source: http://theolleys.wordpress.com)

NFT-Systems

NFT-systems are well suited for use in Aquaponics. They are cheap to construct and therefore are an economical investment. There are some risks connected to NFT, such as clogging of gullies, depending on the diameter of the irrigation capillaries and the construction of the gullies. This may lead to a failure of the irrigation system. The slope needs to be a minimum of 2% and water passage should be about 2 l per min and gully. (Mathis 2014: 21-22)

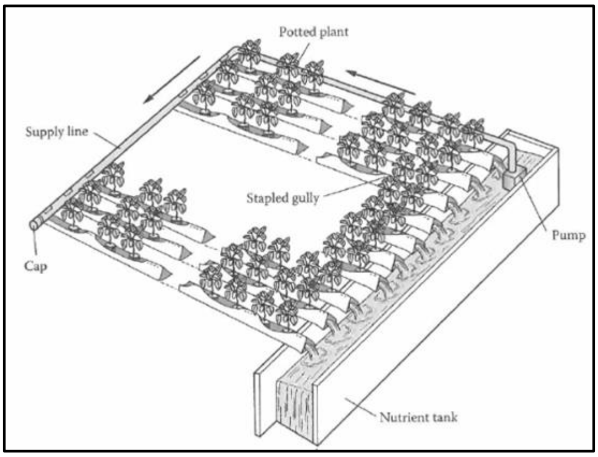


Figure 9: NFT gullies and nutrient tank
(Source: Resh 2013)

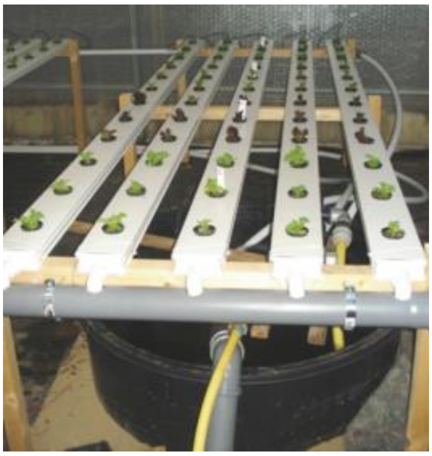


Figure 10: NFT system
(Source: ZHAW)

Aeroponic

Aeroponic is suited for use in Aquaponics to a certain extent. There is a risk that the irrigation system fails, which necessarily threatens production. Depending on the diameter of the irrigation capillaries and the operating hours, there is a risk of the system clogging. Additionally, the equipment is expensive. But production of waste is near zero. (Mathis 2014: 23-24)

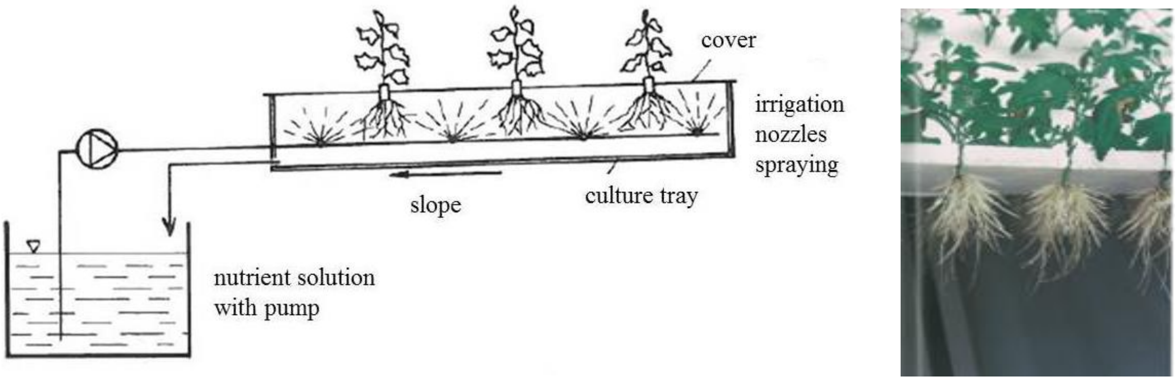


Figure 12: Aeroponic system (Source: Göhler & Molitor 2002)

Bag system

As with Aeroponic, the Bag system is to a certain extent suited for Aquaponics. Since the hydroponic cultivation unit is already developed there are low risks in production. But clogging will occur if the filters don’t work sufficiently. The media structure will allow for sufficient drainage and a continuous water flow, provided that there is sufficient water exchange. In addition, the equipment is expensive and irrigation is controlled through computer. (Mathis 2014: 25-26)

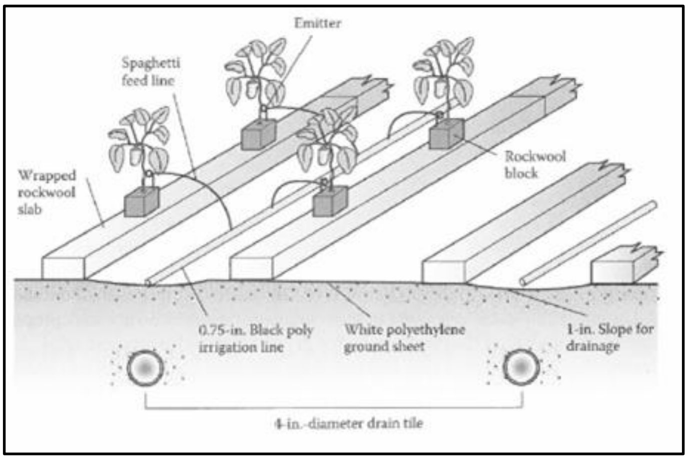


Figure 13: Grodan culture (Source: Resh 2013)

Figure 14: Grodan or Coco coir culture (Source: ZHAW)

Ebb & flow system

Ebb and flow systems are another possibility to use in Aquaponics. Due to the existing water and nutrient buffer in the pot the production risks are reduced. The risk for clogging is low and there is a reduced water exchange. If valves are used the irrigation system and tables will be expensive. (Mathis 2014: 27-28)

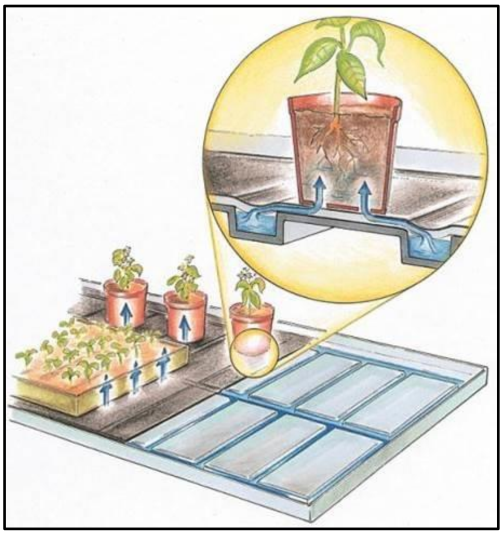


Figure 15: Ebb flow system (Source: www.kriegergmbh.de/Gewaechshauszubehoer/Bewaesserungswanne-1)

Other soilless cultures with different substrates

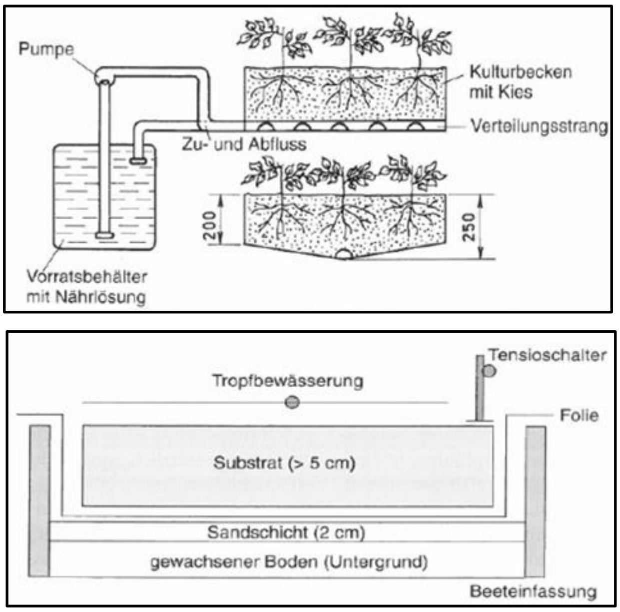


Figure 16: Bed system with gravel as media
(Source: Göhler & Molitor 2002)

Figure 17: Perlite culture (Source: ZHAW)

6 Potential Fish and Crops

Table 2: List of potential fish for use in aquaponics (Rod 2014).

Species	Advantages	Disadvantages
Tilapia (Oreochromis niloticus)	Tilapia is a robust and under good conditions very fast-growing fish. As an omnivorous species, it utilises a large feeding spectrum and can also use vegetable protein sources well.	As a warm water fish, it needs high water temperatures. It is a little known food fish in Europe and cannot compete with other fish as a mass product. Thus the use of Tilapia is limited to niches with special conditions (tropical greenhouses, aquaponic)
Carp (Cyprinus carpio)	A relatively robust and fast-growing fish. Omnivorous, can therefore utilise a wide range of food (vegetable proteins). They can grow well in both warm and cold water.	Isn't always highly valued as a food fish. The market price is rather low. Additionally, carp need comparatively large volumes of water and will damage plants if they can reach them.
Rainbow Trout (Oncorhynchus mykiss)	A relatively robust trout. Is well established in fish farming and a wide range of customized feeding stuff and technical systems exist for this species. The feed conversion ratio is very good and artificial reproduction is reliable. Easy to sell.	Has relatively high oxygen demand and its upper water temperature limit is comparatively narrow (cool water). Mainly utilises animal protein.
Pike-perch (Sander lucioperca)	Under good conditions it grows nicely. Has a quiet temperament.	Not yet (widely) used in aqua-culture. Artificial reproduction not secure and not a lot of options of specific foodstuff and technical infrastructure. Needs warm water for growth and a high amount of animal protein in food.

Table 3: List of potential crops for use in aquaponics

Crop	**Used in study**
Lettuce	Lennard & Leonard 2006; Rakocy 2012: 359; Palm et al. 2014
Cucumbers	Graber & Junge 2009; Palm et al. 2014
Tomatoes	Griessler-Bulc et al. 2012; Graber & Junge 2009; Palm et al. 2014
Aubergine / Eggplant	Graber & Junge 2009; Palm et al. 2014
Capsicum (Pepper)	Palm et al. 2014
Basil	Rakocy et al. 2003; Palm et al. 2014
Culinary Herbs	Mathis 2014; Palm et al. 2014
Microgreens	Mathis 2014

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8 Appendix

8.1 Aquaponic in classrooms as a tool to promote system thinking. Paper by Junge et al.

8.2 The multifunctional aquaponic system at ZHAW used as research and training lab. Paper by Graber et al.