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The multifunctional aquaponic system at ZHAW used as research and training lab

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Abstract

Aquaponics plays a part in promoting sustainable development on different levels in society, and its use is becoming ever more widespread. However, there are not enough trained specialists yet to build and operate such systems. The aim of this paper is to highlight the role of institutions of higher education – like ZHAW – can play to mitigate this deficit. ZHAW has the ability to execute applied research, teaching on BSc and MSc level, and is aiming to increase societal added value concerning education and health. Each of these levels has different demands on the aquaponic system concerning a multitude of factors, such as access, size, construction, climate control, diversity of production methods, recycling and closed loop systems, provision of energy from renewable sources and rainwater harvesting, treatment and use. To evaluate how these objectives are reached, the requirements on the system originating from each level are defined. These are used to evaluate the aquaponic system that was built and operated at ZHAW. Other aquaponic systems in use are compared to the ZHAW system, using the same evaluation criteria. The results show that the ZHAW Aquaponics Lab can reach all target levels, if the aquaponic farm of its spin-off company UrbanFarmers is viewed as an extension of it.

Key words: Aquaponics, Urban farming, Education

1 Introduction

Aquaponics is an innovative sustainable food production system integrating aquaculture with hydroponic vegetal crops (Graber & Junge-Berberovic, 2009, Rakocy et al., 2006). Today Aquaponics became a widely discussed technology (about 1.3 m hits on Google in May 2014, COST Action FA1305: The EU Aquaponics Hub), and it has the potential to play a key role in future food production in the cities. To be able to deal with this emerging technology there is a extended need both in research and education. Research is needed to optimize the production system towards a safe and economical production. The increasing number of aquaponic farms will necessitate the rise of a new profession: the aquaponic farmer. Therefore, appropriate vocational education and training (VET) is needed to transfer the knowledge to operate this system (AQUAVET, an EU Leonardo Transfer of Innovation Project). Also, Aquaponics can be used in education at all other levels: from primary school children (Hofstetter, 2004; Bamert & Albin, 2005; Bollmann - Zuberbuehler et al., 2010) to doctoral studies. At the Institute for Natural Resource Sciences at the Zurich University of Applied Sciences, an aquaponic system was built for the combined use as a research, training, and teaching unit.

2 Material and Methods

A multifunctional aquaponic system can address various goals or stakeholders, which we call levels (Figure 1). To attain all of these, the components of a system have to fulfill various requirements (Table 1).

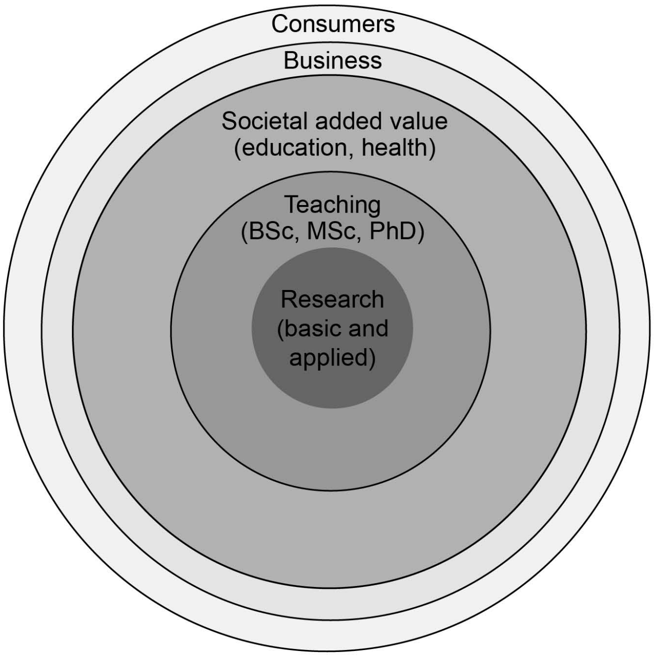

Figure 1: Various levels that a multifunctional aquaponic system could reach. The ZHAW University based Aquaponic Lab strives to directly reach the first three levels. The interaction with business and consumers is indirect: via applied research and education.

Table 1: General requirements for a university based multifunctional aquaponic lab, according to Figure 1.

Aspect	**Research (applied and basic)**	**University Teaching (Bsc, MSc, PhD)**	**Societal added value: Education (K1-12), VET Training, Communication, Health benefits**
Access	Good access for daily work and monitoring, min. 60 cm walkway	Good access for daily work and monitoring, min. 60 cm; Good access for groups	Good access for groups
Size	Reasonable size for scaling up for potential commercial farms	Reasonable size for a good overview	Reasonable size for a good overview
Construction	Easy remodelling[1]	Easy remodelling	Mostly commercial off the shelf elements
Climate control	Advanced	Basic	Basic
Diversity of production methods	Variable according to current research projects [2]	Variable to high: from basic (demonstration of system) to cutting edge (research)	High: from basic (demonstration of system) to cutting edge (demonstration of potential)
Recycling, closed loop systems	Quantitative importance: improving the ecological footprint and thus reducing costs	Quantitative and qualitative importance	Qualitative importance: demonstration of ecological principles
Provision of energy from renewable sources	Quantitative importance: improving the ecological footprint and thus reducing costs	Quantitative and qualitative importance	Qualitative importance: demonstration of ecological principles
Rainwater harvesting, treatment and use	Quantitative importance: improving the ecological footprint and thus reducing costs	Quantitative and qualitative importance	Qualitative importance: demonstration of ecological principles

[1] allows testing of different set-ups
[2] from state of art (aligned with current practices of professional vegetable growers and fish farmers) to cutting edge (testing innovative production methods)

3 Results

3.1 Design of the aquaponic research and training facility

The aquaponic research and training facility is integrated into a heated plastic greenhouse at the ZHAW in Waedenswil with an area of 292 m^2. The cultivation takes place in three identical recirculating aquaculture systems A, B or C, each being connected to a hydroponic production units comprised of three channels for tomato production and three modules à 5 channels for NFT. These tanks are connected to the system as shown in the floor plan (Figure 2 showing connection for System A).

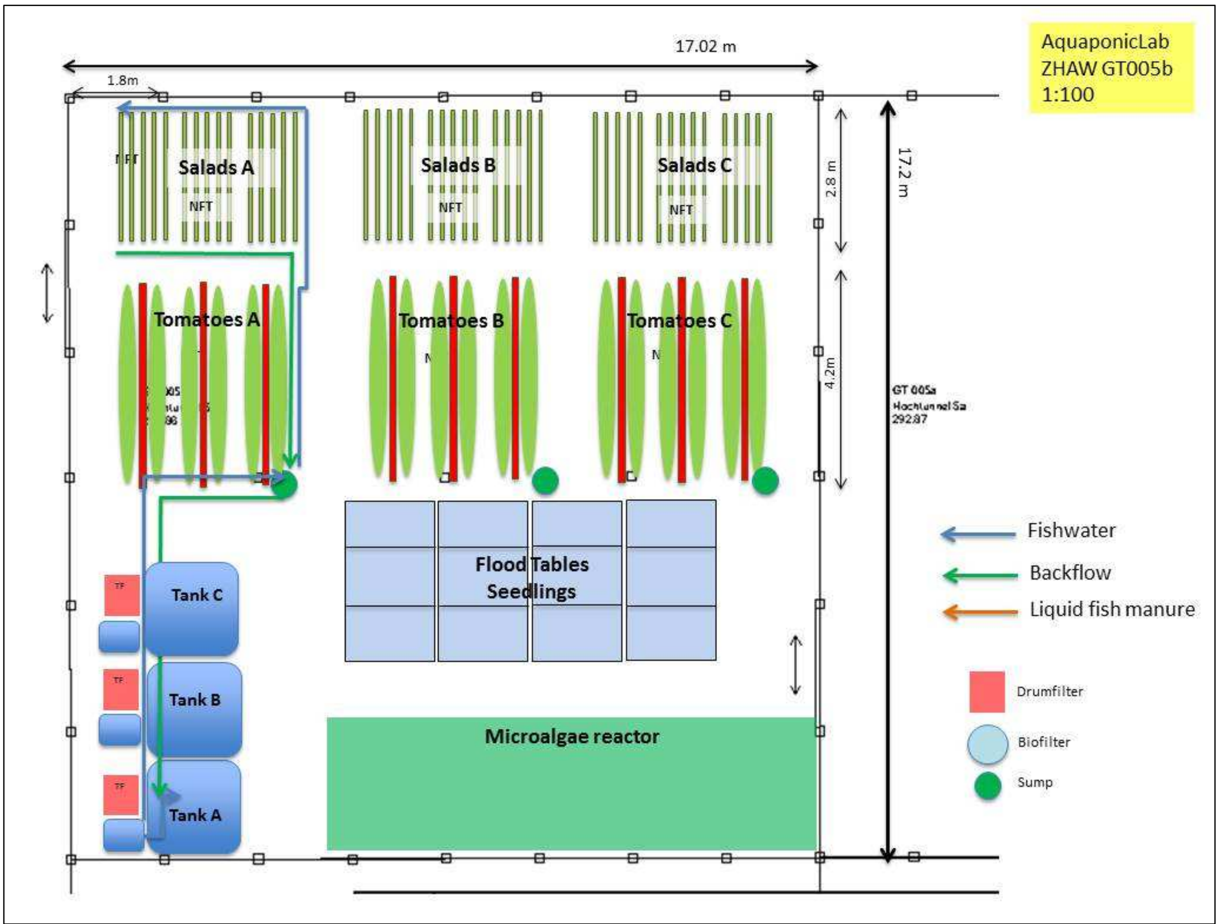

Figure 2: Floor plan of the Aquaponic research and training facility.
The facility is enclosed in a heated plastic greenhouse at the Campus Gruental of ZHAW in Waedenswil, Switzerland (Situation in 2013). The total area is 292 m^2 the area of tomato cultures is 70 m^2, the area of the salad cultures 47m^2.

The greenhouse has automatised climate control, allowing for adjustments according to the plant cultures. The elements of the climate control are heating, aeration (if the temperatures are too high) and humidity control (60-85% relative humidity). At this point, no additional lighting is provided, as the focus was on cultures that can strive at natural ambient lighting.

The evaporated water by the plants is compensated from the fish tanks, and a periodic backflow into the fish tanks takes place from the plant sumps. Both processes are controlled by the "UF-Controller", the electronic control unit of the system. The system is loosing water by drum filter, which is continuously removing fish faeces and causes a loss rate of 10 % of fish water daily. A fresh water supply in the fish tanks from tap water ensures levelling. Each fish tank builds the center and the starting point of one circulating system (Figure 3).

This aquaponic lab was setup during a cooperation project from ZHAW with its spin-off company UrbanFarmers to develop the UF Controller software, and built the world's first commercial aquaponic rooftop farm in Basel.

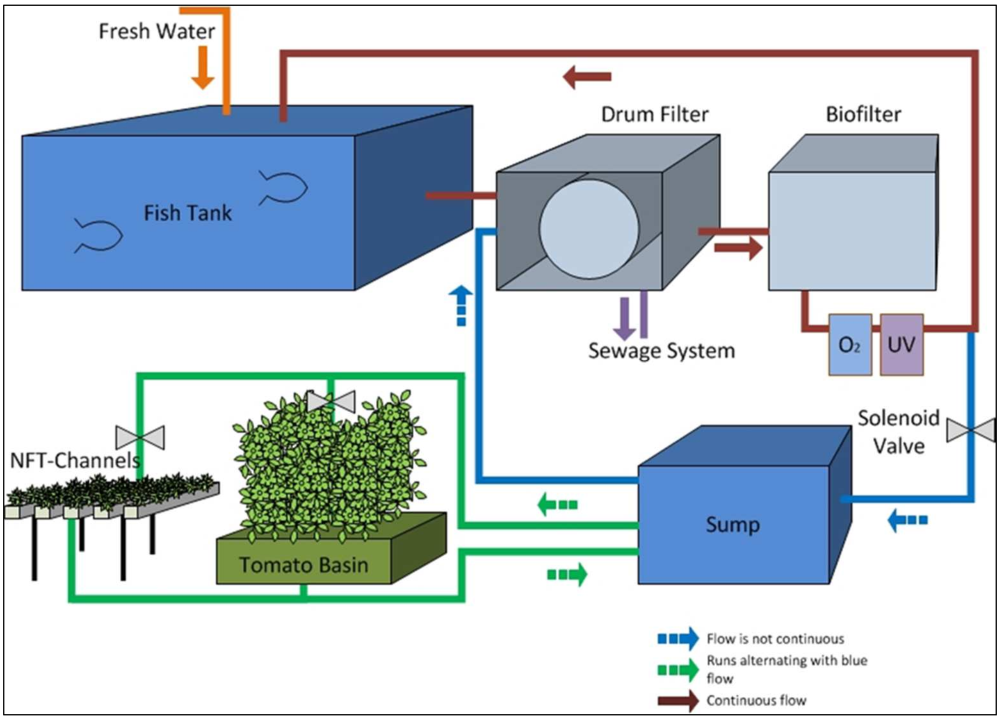

Figure 3: Scheme of one circulating Aquaponic system within the Aquaponic Lab at ZHAW in 2013.

Table 2: Brief technical description of one aquaponic module (the three modules are identical).

Element	**Material**
Fish tank	GFK circular current basin
Tank insulation	XPS 30 mm
Drum filter	Lavair L500 with SPS control
Drum filter base	Kanya System
Drum filter pre-filter	Arkal ¾“
Biofilter	IBC Tank with GEA biocarrier media
OxiJet	LINN OxiJet 5
UV-light	Aqua Ultraviolet UVC-Ozone Combo
Circulation pump	Unitech perfect pond dry 9‘000
Aquaculture piping	Tank outlet: PP 110 mm Pump line: PVC 63 mm
Water supply to plants (time-controlled via UF Controller)	Magnetic valve 1“ 24V NC 32 mm PE piping white
Return pipe from plants (Level-controlled via UF Controller)	Pump Oase Aquarius Universal 4000 32 mm PE piping white
Heater	Gas heater 15 kW, secondary circulation
Heating element	Torgen heat exchanger 1"
Pool cover	Twin wall sheets 6 mm
Oxygen generator	Koi-Teich Oximaxx
Feeder	LINN Profi 5 kg
Controller (Regulates temperature and O_2-dosage in OxiJet)	ARC Controller

As Aquaponic technology is mainly developed for future roof farms in the cities, soilless production is practically mandatory to achieve independency from soil culture and lighter weight of the system. There is a wide array of possible soilless cultivation methods (Figure 4).

The choice of the soilless cultivation method also depends on the sludge management. If there is no sludge separation step between the aquaculture and hydroponic, plants have to be planted in a trickling filter of other substrate that enables sludge recycling. This allows for complete nutrient recycling, but also results in reduced biofilter performance and possibly turbid water. Only extensive fish stocking is possible: limited to 10 kg/m^3. The results of this set-up were reported elsewhere (Graber and Junge-Berberovic 2009).

If other options of soilless cultivation, used by state-of-art vegetable growers, are to be implemented (such as raft cultures, NFT, ebb & flow), a sludge separation step is mandatory. This allows for only partial nutrient recycling, but results in clear water, lower BOD concentrations, lower microbial load, and optimized biofilter performance. It also allows for fish stocking up to 50 kg/m^3. From Mai 2013 to Mai 2014 raft, NFT (nutrient film technology), ebb & flow systems were tested in combination with plants set in a rock-wool substrate.

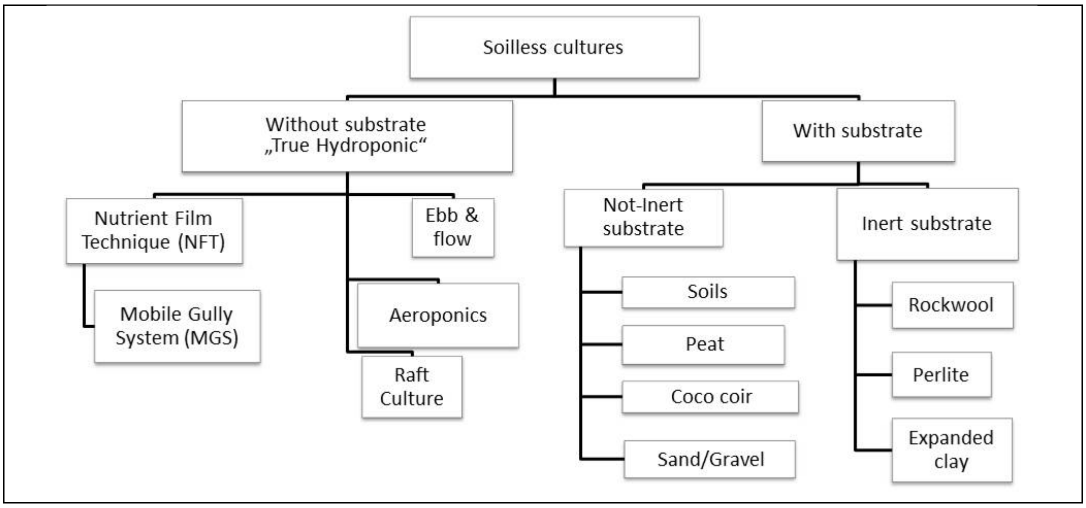

Figure 4. The taxonomy of soilless cultures (Bachmann, D., unpublished).

3.2 Analysis of the fulfilment of requirements

To analyse the fulfilment of the requirements, we constructed an evaluation spider for all eight central categories. As each function has often different requirements in each category, these were evaluated separately.

The evaluation spiders reveal gaps in categories "Provision of energy from renewable sources" and "Rainwater harvesting, treatment and use". Both aspects are important requirements for the sustainability of Aquaponics and should be included in a multifunctional aquaponic lab especially for university teaching and societal added value. It also represents an interesting interdisciplinary topic in regard to the development of building integrated agriculture (BIA) as defined by Caplow (2010). Some pilot studies were made about the energy topic in Aquaponics and it is planned to include these aspects in further research projects.

For university teaching the aspects of "Recycling, closed loop systems" could be demonstrated more clearly. The diversity of the production methods could also be even higher.

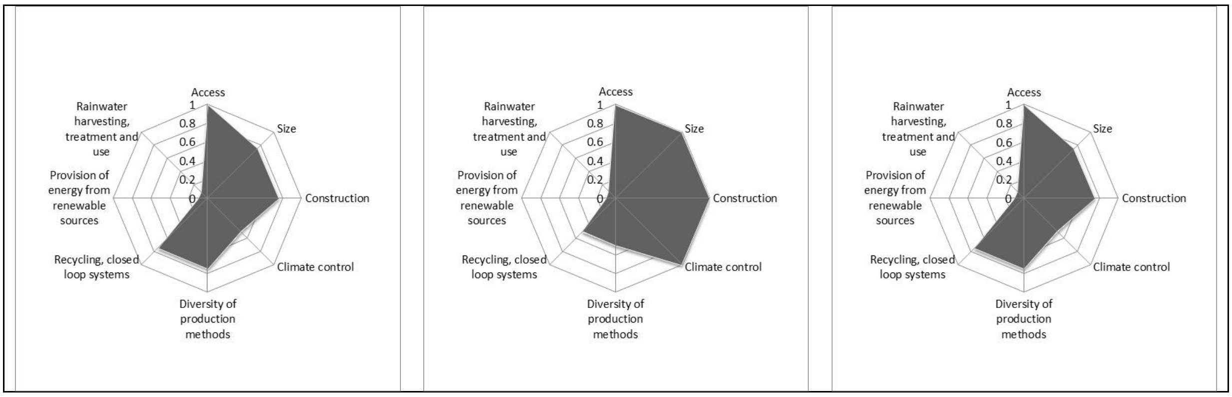

Figure 5. Self-evaluation of the central functions of the Aquaponic Research and Training Facility at ZHAW. From left to right: fulfilment of requirements for applied and basic research, for university teaching, and for the societal added value, as outlined in Table 1.

4 Discussion

4.1 Comparison of the ZHAW Aquaponic Research and Training Facility with other systems

When researching on the Internet, there is a large amount of information on aquaponic systems (Table 3). Taking a closer look, however, there are very few projects that are successful and convincing in their implementation. SweetWaterOrganics (Table 3), for example, was planned and built as a commercial farm, but had to abandon operation after a short period of time due to insufficient finances. A foundation has taken over the farm and now operates it as an educational facility (SweetWaterOrganics, 2014). The City Scape Farms project seems to have been cancelled while still in the planning phase (Cityscape Farms, 2011). These examples show that serious planning and operation according to the current state of research are indispensable for a commercial implementation of an urban aquaponic farm.

However, not all projects have the aim of commercialisation. From the start, the Roof Water-Farm (Table 3) set their focus on research. Projects in urban areas that conduct research also cover the aspect of societal added value.

From the beginning, the facility at the ZHAW only wanted to attain the first three levels (Figure 1) and therefore the Lab was merely built for research and educational purposes. The ZHAW spin-off Urban Farmers complements the ZHAW facility in that it covers the additional two levels of business and consumers. Collaboration between Universities and market players, as seen with Urban Farmers and the ZHAW, can therefore reach all levels of multifunctional systems (Figure 1).

The overview of current aquaponic farms (Table 3) primarily shows that there is still a great need for research. Due to their multifunctional use, facilities such as the one at the ZHAW can contribute to more commercial farms being established successfully.

Table 3: Comparison between several realised or planned Aquaponic Systems.

Farm Operator	**Location**	**Detailed information**	**Size (m^2)**	**Produce (t/annum)**	**Multi-functional system**	**Attained levels (Figure 1)**	**Special focus**
SweetWater Organics	Milwaukee	commercial operation closed; object used for education	not clear (>300)	no data	no	- societal added value	urban agriculture
Cityscape Farms	San Francisco	no object declared website abandoned	not clear	no data	no	- business - consumers	urban agriculture
Roof Water-Farm	Berlin	BLOCK 6 in Berlin-Kreuzberg	50	no data	yes	- research - societal added value	decentralised wastewater treatment
UrbanFarmers AG	Basel	UF001, Basel	260	3 t vegetables 0.6 t fish	yes	-societal added value - business - consumers	urban agriculture, commercial production
ZHAW	Waedenswil	Aquaponic Research and Training Facility	292	-	yes	- research - university teaching - societal added value	education and production methods

Sources: SweetWaterOrganics, 2014; Cityscape Farms, 2011; Roof Water-Farm 2014; Urban Farmers AG 2013; ZHAW (unpublished data), 2014

4.2 The multifunctional use of the system

The multifunctional aquaponic system at the ZHAW is operated since Mai 2013, thus for more than one year now. As a research lab it is has been used for several projects, the main ones being the "*UF Controller: Aquaponic process control system for urban farming*" in collaboration with the ZHAW Spin-Off company UrbanFarmers and funded by the Swiss Commission for Technolgy and Innovation (CTI, Project 13770.3 PFLS-LS), and "*Enhancing safety and security of Aquaponics technology for fish and vegetable cultivation (AQUA-SAFE)*" in collaboration with Trakia University, Stara Zagora, Bulgaria, and funded by the Sciex-NMS^{ch} (Scientific Exchange Programme between Switzerland and the New Member States of the European Union).

As a graduate teaching lab it is regularly involved in curricular activities at bachelor level (Module Ecotechnology, Project Week Environmental Analysis), as well as Bachelor and Master theses, some of these within the Erasmus-Exchange Programme.

The added societal value is derived mostly from educational activities. The lab is used for training within the Leonardo da Vinci Transfer of Innovation Project (Lifelong Learning Programme) "*Introducing Aquaponic in VET: Tools, Teaching Units and Teacher Training (AQUA-VET)*" (www.project.zhaw.ch/de/science/aquavet.html). The predecessor to this lab was involved in the FP6 Science and Society project: "*WasteWaterResource: Introducing ecological engineering to primary schools to increase interest and understanding of natural sciences*" (www.play-with-water.ch). The results were included in a publication that is widely used for teaching sustainability in Switzerland (Bollmann - Zuberbuehler et al., 2010). The Lab is also involved in the only certified education for Aquaculture owners and operators in Switzerland, the "FBA in Aquaculture".

Within the Institute of Natural Resource Sciences, the Ecological Engineering Research Unit collaborates with the Research Unit "Sustainability Communication" which is involved in a wide array of communication, education, and dissemination activities, from Science Weeks and excursions for primary school students, to evening courses and guided tours for adults. By now the Aquaponic Lab is a fixture in these activities. Possible teaching topics include: system thinking, fish culture and physiology, vegetable growing, plant physiology & culture, water quality monitoring, calculation of the nutrient balance and energy balance of the system, biological pest control, system control, aquaponic kitchen: how to prepare home-grown food, use of business tools (calculation of production costs), Life Cycle Analysis, food technology: safety issues, evaluation of produce quality, water treatment technologies, and further on. The possibilities of integrating Aquaponic within a curriculum are practically endless.

Bibliography and sources

Bamert, R., Albin, V. *Aquaponic als Unterrichtsmodell* (online). Term Thesis. Hochschule Waedenswil HSW. 90 pp. 2005. (quoted 07.07.2014). Accessible: http://www.play-with-water.ch/d4/documents/doc_30.pdf.

Bollmann-Zuberbuehler, B., Frischknecht-Tobler, U., Kunz P., Nagel U., Wilhelm Hamiti, S. *Systemdenken fördern: Systemtraining und Unterrichtsreihen zum vernetzten Denken: 1.-9. Schuljahr*. Bern: Schulverlag plus, 2010.

Caplow, T. Building Integrated Agriculture: Philosophy and Practice. In: Heinrich-Böll-Stiftung (eds) (2010) Urban Futures 2030. *Urban Development and Urban Lifestyles of the Future. Volume 5* (English Edition) in the publication series on ecology. Pp. 54-58.

Cityscape Farms: www.cityscapefarms.com (website abandoned)
http://seedstock.com/2011/04/28/sustainable-agriculture-on-the-roof/. Accessed in July 2014.

Graber, A., Junge-Berberovic, R. Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production. *Desalination*, 2009, 246, 1-3, 147–156.

Hofstetter U. *Aquaponic im Unterricht,* Bachelor Thesis, Zürcher Hochschule für Angewandte Wissenschaften ZHAW, Waedenswil. 105 pp. 2004. (quoted 05.07.2014). Accessible: http://www.play-with-water.ch/d4/documents/doc_13.pdf.

Rakocy, J. E., Masser, M. P., & Losordo, T. M. Recirculating aquaculture tank production systems: aquaponics—integrating fish and plant culture, *SRAC publication*, 2006, 454, 1-16.

Rakocy, J., Shultz, R. C., Bailey, D. S., & Thoman, E. S. Aquaponic production of tilapia and basil: comparing a batch and staggered cropping system. In *South Pacific Soilless Culture Conference-SPSCC 648*. pp. 63-69, 2003.

Roof Water-Farm: www.roofwaterfarm.com Accessed in July 2014.

SweetWaterOrganics: http://sweetwater-organic.com/ Accessed in July 2014.

Urban Farmers AG: www.urbanfarmers.com Accessed in July 2014.

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