Adequate Design for Aquaponics with Case Study

Heba Mosalam[a,*], Abanoub Shenouda[b], Yasmin Kamh [c], Esraa Sami[d] and Rasha Elkholy[e]

[a]Assist. Prof., Electromechanical Department, Faculty of Engineering, Heliopolis University, Egypt
[b]Teaching Assist., Civil Department, Faculty of Engineering, Heliopolis University, Egypt
[c]Lecturer Assist., Architecture Department, Heliopolis University, Egypt
[d] Researcher, Faculty of Engineering Heliopolis University, Egypt
[e] Professor, Dean, Faculty of Engineering Heliopolis University, Egypt

***Abstract*:** *Aquaponics is a food production method that combines the traditional hydroponic and aquaculture to form a closed-loop system that, through symbiosis, re-circulates all the water and Nutrients in order to grow terrestrial plants and aquatic life. This study comes as an outcome of the Trinex project to manage water, energy and food nexus as a kind of building an integrated system, monitoring its malfunction and redesign it after monitoring it enhanced performance. The WEF Nexus is the pillar with which the future well-being of Egypt can be severely impacted. The TriNex WEF project supported Heliopolis University for Sustainable Development (HUSD) to build its first pilot project for the water, energy and food. Discussing the cons. And pros. Of the HUSD aquaponic and presetting an optimized the performance of a similar scale designs of aquaponics. Moreover, Heliopolis aquaponic –the used system- has shown enhanced performance after applying modifications to the mechanical system as well as enhancing its water quality.*

Keywords: *Aquapoinc, Reverse osmosis, Photovoltaic, Index, Tilapia, Water parameters*

1. Introduction

According to the World Bank report (2016), the world needs to produce at least 50% more food to feed 9 billion people by 2050. However, due to climate change, the crop yields will be cut by more than 25%. Moreover, climate change is causing depletion at exaggerated rates for land, biodiversity, oceans, forests and other forms of natural capital. Therefore, unless humans change how they grow their food and manage their natural capitals, food security- especially for developing countries- will be at risk. Based on this goal , the TriNex project adapted by EU and the WEF nexus synergy between water, energy and food issues mainly in Egypt was created [2]

One of the research applications for the WEF Nexus in HU- case study- in Egypt is its aquaponic. In general, aquaponics adapt the art of growing crops with growing fish feces. It is the integration of aquaculture with hydroponic plant production [3]. In aquaculture, nutrient-rich water is removed from the system and discharged to the beds on a regular basis to manage nutrient levels within the system. However, in aquaponics, this nutrient-rich water is seen as a commodity instead of a waste, and is used to grow plants [4]. Once the plants have utilized the nutrients and absorbed them from water, the water is returned to the fish for further fish culture, and the perpetual cycle begins again[5], [6]

This balanced system is mainly consists of two parts: Hydroponics and Aquaculture. Hydroponics –also known as the Raft System and Deep Water Culture- is the process of growing food in an inert medium by controlling and adding nutrients without soil [7]. Aquaculture is the cultivation of aquatic animals or plants for food [8] .

This integrated system has several operational advantages, such as: labour reduction, high production rate, providing income from two separate products, which are: aquaculture waste and biofiltration which is considered to be critical for the conversion of toxic ammonia to nitrate plant fertilizer [4]. In addition to the previous advantages, it controls the PH levels which leads to efficient nitrification [9].

https://doi.org/10.17758/ERPUB.ER1217228

Many researchers have shown that high PH plants display nutrient deficiencies and on contradiction, low PH ammonia accumulates to toxic levels for fish[10],[11], [12] and[3].

2. Rationale for Upgrading the Old-HUSD Used System

The modifications applied to the old aquaponic system in HUSD started on 13th October 2016 after operating the system on 10th July 2016, to enhance the performance of this system and increase the liveability of the plants-irrigated by the water produced by this system too. The procedures started by stopping the fish feeding for two days to repair and enhance the balancing system.

3. Optimization Design Criteria for the Used Aquaponic System

The design criteria used for the HUSD Aquaponic system in this section are illustrated through the following aspects: the used pump and flow rate, the source of the system's refill water and ways adapted to ensure the system's aeration. Moreover, this section presents a further explanation for the before and after modifications which were made to enhance the system's performance.

3.1. The Used HUSD Pump and its Flow Rate

The HUSD Aquaponic system contains a domestic pump, which is capable of pumping 38 litres of water per minute, hanged 1.75 meters below the water level of the fish tank inside the a protective pipe. Regarding the fluid dynamics, vortices are a major component of turbulent flow [13]. A vortex is an area of a fluid possessing a torrent, often a swirling motion, around an imaginary axis, either straight or curved. This movement pattern is known as vortex flow (Kida, 2001).

Besides, this system is built with polyamide impellers and corrosion free components to ensure: firstly, its longevity and, secondly, that no toxic and alien substances are leached to the circulating water. The power usage for the pump is at 0.4hp. It's equipped with a floating switch that renders the pump, hence; preventing it from working if the water level in the fish tank depletes too much. Hence, the water level in the fish tank can't neither going beneath the half mark, nor counting evaporation.

Moreover, this pump was not optimized for this system, it was, however, ensured not to be lacking in capacity. Therefore, to optimize the pump, it was replaced with subsurface irrigation pump with 100litre of water per minute flow rate and power consumption of 1hp in the upgraded system.

3.2. Sources of Refilling the Water for the System and its Aeration

Water samples have been tested before using the RO unit to supplement the residual and disposal water. The tests made on municipal water, well water and surface water. For the municipal water, tests showed that it might contain chlorine, which is toxic to fish. Besides, chloramine must be broken up with a sulphur compound. On the other hand, tests for the well water showed that it contained pesticides and contaminations, which decrease the Dissolved Oxygen and increase the Carbon dioxide according to several researches [14].

Finally, for the surface water, the tests showed that it contained chlorine, algae, fungi and focal coliforms. The following parameters are the sample which was taken to the RO product and their removal rates are:

- Turbidity ~100 %, TDS 90%-99 %, TOC 90%-99% , Chlorides 90%-99%, Colour 95%-99% , Iron& Manganese ~100%

In addition, the supplements of the following items were needed: Iron (Chelated Fe),Calcium Hydroxide (CaHo2) and Potassium Hydroxide (KoH) to enhance the health of the plants. One of the modifications applied to the aquaponic system was upgrading the pumps, the plumping system and insuring the good performance of the aeration. As the fish, plants and bacteria in any aquaponic system require adequate levels of dissolved Oxygen (DO) to maximize health and growth rates.

3.3. Flow Rate Parameters for the Fish Tank

Firstly, the water retention time within tanks is 1-1.5 hours. Secondly, the capacity of one fish tank equals 1500 Litres, hence, the total capacity of the 4 fish tanks 6000 litres. Thirdly, the flow rate needed in the system should be 100 litres per minute to upgrade the pump speed from 30 litres per min. Fourthly, the capacity of the used clarifier container equals to 1000 Litres. Thus, the flow rate of the clarifier is 50 litres per minute. Finally, the retention time for clarifier is 20 minutes.

3.4. Fish Feeding Ratio

The ratio between fish and plants is based on the feeding rate ratio (amount of feed fed to the fish daily per square meter of the plant growing area). For the HUSD-aquaponic, the optimum ratio varies from 60 to 100 grams per square meter per day. For Example: 80 grams fodder per square meters plant(standard value from 60-100 gm depending on the type of crop).This estimation is the average feeding /m2 per day. Number of plant beds used is three. Each bed with an area equals 13.2 square meters (12 meters* 1.1meters), hence, the total area of these beds equals 40 square meter. Total quantity for fish food is 3.2 Kilogram per day. Fish feed by pellets of 30 percent protein and it has to be medium sized from 3-4 millimeters and to be designed to float on the surface. According to the fish's tanks temperature, the fishes are fed 3 times per day in winter and 4 times per day in summer

3.5. Before and After Modifications for the Used HUSD Aquaponic System

Table 1 shows the modifications applied to the old used- system as a way to improve its performance. These modifications vary from increasing the power of the used pump, then changing the location and the materials for some parts in the mechanical parts of the system to adding small nets.

TABLE I: Modifications applied to the used Aquaponic system in HU

Before modification	After modification	Reason for the modification
Power of the pump=0.5 hp	Power of the pump= 1hp	Increase the flow rate from 30 to 100 l/m
The pipe coming out of the bottom of the fish tank was connected vertically to the top surface of the container(Fig.1)	-The clarifier has been raised above the fish tank by 5cm (Fig.2) -The pipe from the fish tank has been positioned tangentially to be near the lower middle of the clarifier. -A barrier has been inserted vertically in the middle of the clarifier	-Forcing the water to swirl in a circular motion inside the container. -Working on accumulating the solid waste more effectively at the bottom of the container. Hence, allowing only the micro waste particles to move to the net filter
Small nets have been placed on the openings of the pipes coming from the net filter (Fig.3)	Increase the amount of nets and size in all net filters	-To prevent small fishes from entering the water and to remove fine undissolved
All connections were made of PVC which caused them to detach due to the heat coming out of the blower.	The PVC connections have been exchanged with metal ones (Fig.4)	-To endure the heat in a more effective way

Fig. 1: The initial design for the Clarifier

Fig.2: The redesign for the Clarifier

Fig. 3: Adding small nets to the Degassing stage

Fig.4: Metal Connection

4. Measurements of Water Quality Parameters and Tests

Values of water quality parameters have been measured using three methods: Pro-Plus water measuring parameters- portal, Nilebot online monitoring system and JBL test lab Kits. Currently, the HUSD Aquaponic system has two water quality monitoring schedules: daily for DO, Temperature, PH and total ammonia nitrogen as a slight aeration in these parameters highly impact the fish and weekly test for: Nitrite, Nitrate, Iron, Phosphorus, Alkalinity and Potassium. The standard values for the water quality which have been used as limits in this research are found in Table 2. This table shows: the water quality standards at the degasing process based on a similar research conducted by [9] and the values of water quality before and after the redesign of the HUSD Aquaponic.

TABLE II: Water quality parameters and before and after values

	Ph		**DO**		**TDS**	**NH_4**		**NO_2**		**NO_3**		**Fe**	
Standard	Opt. 6.5-7	Crit. 5 or 10	Opt. > 5	Crit. < 3	Opt. 400- 800	Opt. 1.0	Crit. < 0.1	Opt. > 1	Crit. 0.8-2	Opt. > 3	Crit. 30-300	Opt. < 20	Crit. 2
Before	7.5		1.5		500	0.1		0.1		21		0.08	
After	6.9		5.6		500	0.1		0.05		50		1.2	

During the laboratorial measurements of water temperature for the fish tank on several days, a direct relationship has been noticed between the temperature and the nitrification level for the water (NO3) and is represented in Fig.5. This figure shows that the nitrification is affected if the weather's temperature is 18 degrees in the winter season. Therefore, as a way to overcome this problem, a reduction for the feeding times to twice instead of three times per day is required. The temperature for optimum growth of nitrifying bacteria is between 25° – 30° C (77° – 86° Fahrenheit). Growth rate is decreased by 50% at 18° C. Growth rate is decreased by 75% at 8° C – 15.5° C. No activity will occur at 4° C. Nitrifying bacteria will die at 0° C and 49° C. Nitrobacter sp. is less tolerant of low temperatures than Nitrosomonas sp. In cold water systems, care must be taken to monitor the accumulation of nitrites.

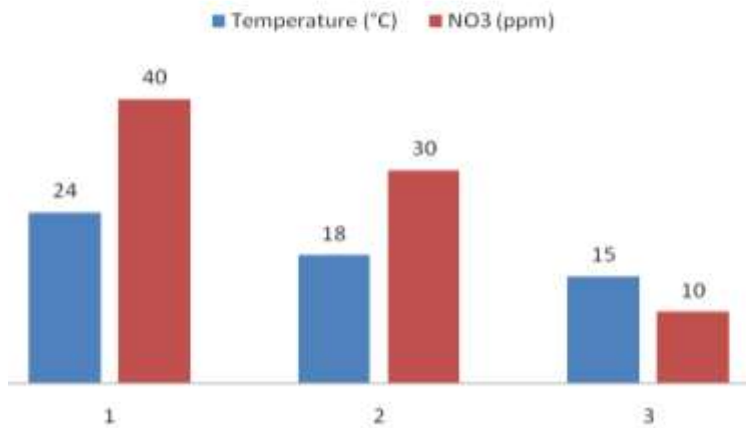

Fig.5: Direct relationship between the temperate of water in the HU-fish tank and NO_3

5. WEF Nexus HUSD Aquaponic Index (WEFNHUSDI)

An Index has been developed based on the most effective parameters in enhancing the efficiency of productivity for fish in the HUSD-Aquaponic. This index can be applied for other aquaponics with the same design criteria that were mentioned in Section 3.

Table 3 shows the parameters of the Water, Energy and Food Nexus Heliopolis University for Sustainable Development Index (WEFNHUSDI), standard values for operating the HUSD Aquaponic, values before and after normalization. The selected index parameters are considered to be the most effective parameters on increasing the efficiency of fish productivity from HUSD Aquaponic based on the laboratorial measurements before and after the modifications to the system. These parameters are: water quality parameters for the degassing, water temperature for the fish tank, Food Conversion Ratio (FCR) and the power performance of the pump. FCR is a measure of an animal's efficiency in converting feed mass into increases of the desired output [15] .In order to ease the calculations, an assumption was made that all these parameters have the same weight, hence, the same significince at increasing the efficiency of the fish productivity.

Besides, this table represents the standard values for operating the HUSD Aquaponic. These values are based on several researches in the field of best conditions for growing Tilapia through aquaponics [16], [17].Third column shows the non-normalized values for the Index parameters. These values have been measured through this study as have mentioned in Section 4. Finally, the fourth column represents the normalized values by conducting the percentage of the non-normalized value from the mean of the standard values. The mean values have been selected because it is safer than the minimum values and more realistic than the maximum values for this type of small scale aquaponic. However, for the values of the parameters that have exceeded 100%, indicate that the modifications made to the aquaponic have enhanced these parameters; till they become close to the maximum values within the standard values. Hence, they are still acceptable.

TABLE III: WEF Nexus HU Aquaponic Index

Index Parameters		Standard values for operating HU Aquaponic			Non-normalized values		Normalized values	
		min.	max.	mean	Before modification	After modification	Before modification	After modification
Water quality standard at the Degasing (ppm)	Ph	5	10	7.5	7.5	6.9	100%	92%
	DO	2	7	4.5	1.5	5.6	33%	124%
	TDS	200	1500	850	500	500	59%	59%
	NH4	0	1	0.5	0.1	0.1	20%	20%
	NO2	0.8	3	1.9	0.1	0.05	5%	3%
	NO3	28	300	164	21	50	13%	30%
	Fe	2	4	3	0.08	1.2	3%	40%
Water temperature (oC)		18	28	23	20	20	87%	87%
FCR		1.7		1.7	1.7	1.7	100%	100%
Power performance(hp)		0.25	1	0.625	0.5	1	80%	160%

Microsoft Excel has been used to calculate these values and develop a radar diagram for the "before and after" medications (Fig.1-4). It can be seen clearly from Fig.6 the effects of the modifications on some of the previous mentioned parameters. A Rader diagram makes the measurement before and after the redesign more useful for visually- choosing which parameter has similar values hence, no difference before and after the modification. Moreover, it helps in facilitating which parameters are scoring the standard values and illustrate the idealization for displaying the performance.

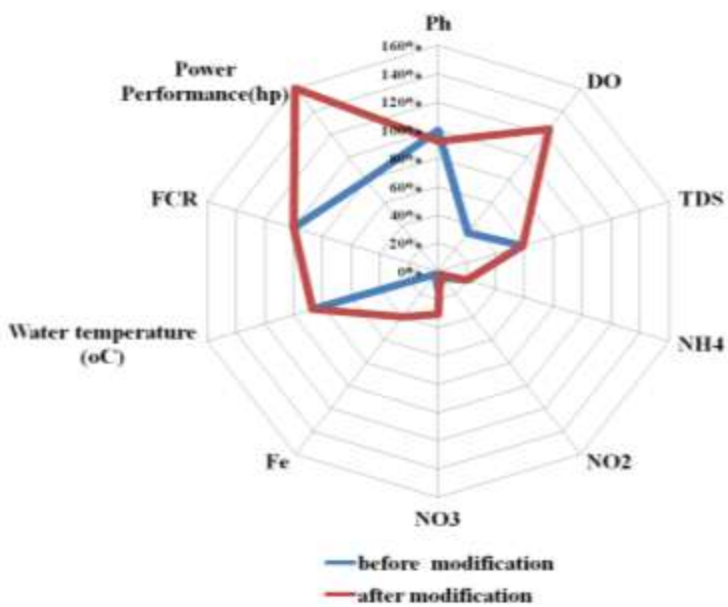

Fig.6: Radar Diagram for the WEFNHUI

6. Plant Reconstruction

Before redesigning the system the following were measured as conditions for the plants: Plantation zone of (Basil – Chilli pepper – Cabbage) with an area 45 meters square, deficiency in nitrates (21 milligram per litre from 28-300 milligram per litre) caused leaves to appear pale green because they are unable to make sufficient chlorophyll, lack of Iron (0.08 milligram per litre from 2 milligram per litre) caused interveinal chlorosis where the areas between the veins appeared yellow in colour ,and the v media was a mixture of peat moss and perlite. After redesigning the system: Plantation area becomes 90 square meters, Augmentation of nitrates (50 milligram per litre) dynamically changed the appearance of the plants to appear vigorous, Adding 250 gm. of chelated Fe significantly enhanced the interveinalchlorosis of the leaves, and the media has been replaced with a mixture of coco fibre and perlite 70:30, because peat- moss (the previous media) is prone topythium. Pesticides must not be used to control insects and plants diseases because they are toxic to fish and none have been approved for use in food fish culture, therapeutics for treatment fish parasites and diseases may harm beneficial bacteria and vegetables may absorb and concentrate them and biological control methods are the only option for controlling insects and diseases.

7. Findings and Conclusion

The findings and conclusions of this work can be classified in to the following four sub-sections. First subsection discusses the general requirements for the optimum system. The second and third parts show the modifications that have been done to the plants beds and mechanical system, respectively.

7.1. General

The greenhouse has to be covered with black tarpaulin in winter over the fish tanks side to keep the warmth of the water in the fish tanks as tilapia fish prefers temperature in a range of 25-35 Celsius degree. And the tarpaulin is exchanged in summer with white ones. All air leakages have to be sealed properly in the greenhouse for two reasons: to benefit efficiently out of the cooling system, and to prevent any cause of pest and diseases. As for the aeration, more air stones need to be added to the plant beds and for the fish tanks it needs to be replaced by new ones. Having in consideration that air stones in the fish tanks need to be rinsed and cleaned weekly and monthly for the plant beds' ones. A lux meter is required to measure the light intensity in order to choose the suitable plants and the appropriate shading nets, temperature sensor need to be placed in the rear area of the greenhouse at plant level in order to have the actual reading of air temperature the plants require , as well as a net should be placed in the degassing and on the openings of the plant bed pipes to prevent any small fish from entering the plant beds because fish can eat the roots of the plants and could cause blockage in the pipes. Net filters containers have to be filled with more nets in order to reduce the waste particles going to the degas, thus, reducing the wastes going to the plant beds also proper fish fodder storage is needed and it must be covered and sealed properly to prevent rats from eating it which means a small and dry storage room is required, and a small tank with a pump in it is needed for controlling the fertilizers entering the system to prevent any shocks for the fish and to maintain all the additional required nutrients. The water level in the sump should be at a level of 1.5 meters and have in consideration that it has to be above the non-return valve by about 20 centimeters for safety also it is recommended to have a Quarantine to adapt the small bought fishes to the temperature and pH of the water in the system and ease the selection of the healthy well weighted ones (20-25 gram). As well as the fish tanks should be rolled with insulation rollers to keep the warmth of the water, the small fishes require pelletized floating feed 1 mm in size and the estimated time of feeding is 6 weeks if the small fish in tanks have to be between 5-20 gram.

7.2. Plant Beds

In order to increase the area of rooting, hence, having more vigorous plant, getting new net cups of 5 centimetres height and of 5 centimetres diameter slotted from the sides and bottom should be taken in consideration. Moreover, getting new raft sheets of 3 centimetres thickness because a space of 3–4 centimetres should be left between the cups and the water body. This allows air to circulate around the top section of the plant roots, and it also reduces the need for air stones in the canal as sufficient amounts of oxygen in the air are supplied to the roots. Another advantage of this method is the avoidance of direct contact of the plant stems with water, which reduces the risks of plant diseases (e.g. roots knot) at the collar zone. Moreover, the increased ventilation as a result of the increased air space favours heat dissipation from water, which is ideal in hot climates.

Plants need to be controlled with biological control to avoid any diseases. The two main organisms used to this purpose are bacillus thuringiensis (Bt) and beauvariabassiana. It is recommended to spray them on leaves 3 times per week. With dilution 1:10 for resistance and 1:2 for protection and leafy green plants do extremely well in aquaponics along with some of the most popular fruiting vegetables, including tomatoes, cucumbers and peppers. Fish provides the plants with all the nutrients (10 out of 13) it needs; excluding (Fe, CA,and K) so these three nutrients need to be added manually. Iron is regularly added as chelated Iron to reach concentrations of about 2 milligram per litres. Calcium and potassium are added when buffering the water to correct the PH, as nitrification is an acidifying process. These are added as Calcium Hydroxide and Potassium Hydroxide.

8. Acknowledgements

This research would not have been possible without the kind support and help of many individuals in Heliopolis University for Sustainable Development, Egypt. The researchers express their deepest gratitude to all of them. The researchers also thank Ahmed Sultan (Project and Research Department , Heliopolis University) and Yousuf Nuckcheddy (Plants Research Centre, SEKEM), for technical support that greatly improved the manuscript.

9. References

[1] T. W. Bank, “Climate Action Plan 2016-2020,” 2016.

[2] O. and S. Development Economics visc Presidency, Team, “Food Prices and Poverty,” 2016.

[3] W. Lennard, “Aquaponic solutions,” 2013. [Online]. Available: http://www.aquaponic.com.au/aquaponics.htm. [Accessed: 05-Feb-2017].

[4] A. Graber and R. Junge, “Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production,” *Desalination*, vol. 246, no. 1–3, pp. 147–156, 2009.
https://doi.org/10.1016/j.desal.2008.03.048

[5] K. P. M. K. Akil, M. S. Sivasakthi, “Aquaponics-The Future Farming,” *Int. J. Innov. Res. Technol. Sci. Eng.*, vol. 2, no. 4.

[6] M. R. Maghami, H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad, and S. Hajighorbani, “Power loss due to soiling on solar panel: A review,” *Renewable and Sustainable Energy Reviews*, vol. 59. 2016.

[7] R. V. Tyson, D. D. Treadwel, and E. H. Simonne, “Opportunities and challenges to sustainability in aquaponic systems,” *HortTechnology*, vol. 21, no. 1. pp. 1–13, 2011.

[8] M. F. Saaid, N. A. M. Yahya, M. Z. H. Noor, and M. S. A. M. Ali, “A development of an automatic microcontroller system for Deep Water Culture (DWC),” in *Proceedings - 2013 IEEE 9th International Colloquium on Signal Processing and its Applications, CSPA 2013*, 2013, pp. 328–332.
https://doi.org/10.1109/CSPA.2013.6530066

[9] C. Somerville, M. Cohen, E. Pantanella, A. Stankus, and A. Lovatelli, *Small-scale aquaponic food production. Integrated fish and plant farming*. 2014.

[10] R. V. Thurston, R. C. Russo, and G. A. Vinogradov, “Ammonia toxicity to fishes. Effect of pH on the toxicity of the un-ionized ammonia species,” *Environmental Science and Technology*, vol. 15, no. 7. pp. 837–840, 1981.
https://doi.org/10.1021/es00089a012

[11] W. A. Lennard and B. V. Leonard, “A comparison of reciprocating flow versus constant flow in an integrated, gravel bed, aquaponic test system,” *Aquac. Int.*, 2004.

[12] W. Lennard, “Aquaponic System Design Parameters : Fish to Plant Ratios (Feeding Rate Ratios),” 2012.

[13] K. M. Buzby and L. S. Lin, “Scaling aquaponic systems: Balancing plant uptake with fish output,” *Aquac. Eng.*, vol. 63, pp. 39–44, 2014.
https://doi.org/10.1016/j.aquaeng.2014.09.002

[14] J. Rakocy, “Design and Operation of an Aquaponics System,” *Panorama Acuícola Magazine*, 2002.

[15] K. U. . P. H. W., "Effects of fish biology on ebb and flow aquaponical cultured herbs in northern Germany (Mecklenburg Western Pomerania)," *Aquaculture*, vol. 466, pp. 51–63, 2017.
https://doi.org/10.1016/j.aquaculture.2016.09.025

[16] and D. C. Tyson, R., R. Hochmuth, "Hydroponic vegetable production in Florida," *Univ. Florida Hortic. Sci. Dep. Doc. HS405*, 2013.

[17] A. Pattilo, "Aquaponic System Design and Management," *Aquac. Ext.*, pp. 1–67, 2013.