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AQUAPONICS IN THE QUEST FOR SUSTAINABILITY

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Potential of Aquaponics in the Quest for Sustainability[1]

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ABSTRACT

Global environmental, economic and social challenges drive the need for new and improved solutions for food production and consumption. Food production within a sustainability corridor craves for innovations which exceeds traditional paradigms. Development and adoption of new and smart technologies is a potential solution for questions related to climate change, loss of soil fertility and biodiversity, scarcity of resources, and shortage of drinking water Which finally leads to sustainability.One approach that promises to address these issues is Aquaponics. It consists of two technologies: recirculation aquaculture systems (RAS) and hydroponics (plant production in water, without soil) in a controlled management and system. The main goal of the new concept for aquaponics is to improve sustainability and productivity concomitant with lowering environmental emissions. There is a growing interest in aquaponics because it can be practiced in nontraditional locations for agriculture such as inside water house and on marginal lands.

[1] A seminar paper presented at the graduate seminar course AER 598 on 13th Sept 2018.

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CHAPTER I

INTRODUCTION

Aquaponics is the symbiotic integration of hydroponics (e.g. soilless systems for crop production) and aquaculture (e.g. aquatic animal farming) to constantly produce plant and animal products. In this system, aquatic animals excrete waste, bacteria convert the waste into nutrients, and plants remove the nutrients and improve water quality for the aquatic animals. Aquaponics is a sustainable food production system of integrating aquaculture with hydroponic vegetable crops that can play a crucial role in the future of environmental and socio-economic sustainability. Aquaponics is about combining hydroponic production of plants and the aquaculture production of fish into a sustainable agriculture system that uses natural biological cycles to supply nitrogen and minimizes the use of other nonrenewable resources and thus economic benefit is provided. There is various system and media for producing hydroponic crops such as bench bed, nutrient film technique, floating raft, rockwool, perlite, and pine bark (Tyson *et al*.,2011). Essential management requirements like water quality maintenance and biofilter nitrification for aquaculture is important to be integrated with the hydroponics to successfully Develop and adopt an intensive aquaponic systems. The aquaponics system emphasizes on improving sustainability through management and integration of the living components [plants and nitrifying bacteria (*Nitrosomonas* spp. and *Nitrobacter* spp.)] and the biofilter system. Aquaponic systems aim to exploit the advantages of aquaculture and hydroponic systems (Simeonidou *et al*.,2012). Improved water and nutrient use efficiency and conservation is ensured in this way. Challenges to sustainability center around balancing the aquaponic system environment for the optimum growth of three organisms, maximizing production outputs and minimizing effluent discharges to the environment. Aquaponics is a bio-integrated system that links recirculating aquaculture with hydroponic vegetable, flower, and/or herb production (Diver *et al*.,2000). Aquaponics provide vegetable production system that integrates soilless cultivation. Plants gets nutrients from fish waste water and convert metabolites which are toxic to fish. It is totally an environmental-friendly production system due to its full recycling capacity of waste and nutrients.

Objectives

This review paper is directed towards achieving the following objectives:

- To ascertain the potentials and scope of aquaponics
- To know about the sustainability of aquaponics

CHAPTER II

MATERIALS & METHODS

This seminar paper is exclusively a review paper. All data and information were collected and used from secondary sources. This seminar paper has been complied through reading of different. journals, newsletters, souvenir, consultancy report that are available in the Internet. Finally, this seminar paper was prepared with the consultation of my respective major professor and honorable seminar course instructors.

CHAPTER III

REVIEW OF THE MAJOR FINDINGS

In line with the objectives of this review paper, the findings are discussed hereunder:

3.1 Potential and scope of aquaponics

There is global concern about how future generation will provide more of food sustainability. Agriculture have substantial impact on natural resources. The conversion of natural land to agriculture. nutrient leaching, the use of chemicals are all serious issues. The potential of an opportunities for Aquaponics can be viewed through multiple lenses, including its contribution to community transformation. (veludo *et al.*,2012). Closing the loop between crop and animal is seen as the only way to improve water and nutrient efficiency and reduce waste. However, in this case would make further contribution to sustainability.

Table 1. Environmental, economic and social impacts of aquaponics

Sl no.	Category	Impacts
01	Environmental	(1) Use and recycling of water resources (2) Energy consumption & production (3) Recycling of organic waste (4) New landscape opportunities
02	economic	(1) Increased food production (2) allows for the utilization of unemployed labor and land (3) using the waste stream to provide total energy needs of an aquaponics system.
03	Social	(1) improving community food security (2) providing a source of relatively cheap protein (3) important to low-income individuals in both developing and developed countries.

Sources: Anonymous (2016)

Aquaponics has potentiality to improve the livelihoods of households and communities. Fish is an important source of protein in lowland medium income countries and vegetables improve nutrition (Tacon and Metian,2013). Aquaponics can increase food security and the food sovereignty.

However technical skill and knowledge is needed to start commercially intensive aquaponics system. Under favorable climatic conditions (tropics and subtropics), aquaponic systems may be very simple, consisting of uninsulated outdoor units. Little and Bunting (2015) state that very few inputs are needed for a basic unit. Depending on the specific conditions, aquaponics can provide a sustainable food source in low and medium income countries, especially where climate conditions are favorable. Aquaponics has beneficial reductions for some environmental impacts associated with food production. Generally, there are three type of aquaponics system:

Home-based aquaponics (HA)

Food products for local consumption is produced from Home-based aquaponics. This system can be adopted as a hobby to spend time just like home gardening. Home based types is mostly preferable for hotels, prisons, supermarkets, and shopping malls as ideal settings. In the developing countries, self-sufficiency through HA can play vital role in family income generation. In the developed countries, HA is also decreasing the risk of obesity and unhealthy diets due to both the quantity and the quality of protein, fruit and vegetable uptake were increased significantly by home activities (Somerville *et al.*, 2014).

Factory-based aquaponics (FA)

Factory-based aquaponics (FA) is an industrial food production system that is intended for international trade and subject to the regulations of the receiving market. Either fresh water aquaponics or seawater aquaponics can be developed as this model. Seawater aquaponics may exhibit more economic benefits for seafood production and the low-salinity or high-salinity marine plants are used (Waller *et al*., 2015). Energy efficiency of cultivation facilities is a very important parameter for the success, and food productivity is also another parameter to evaluate cost-effectiveness.This model of aquaponics can reduce operational costs by increasing fish productivity and harvest of vegetables. The largest factory-based aquaponics system reported is only 6,000 m^2 that was established in Spain, producing up to 125 ton of tilapia, 15 ton of tomatoes, 6 ton of strawberries and up to 50,000 salads per year (Thorarinsdottir,2015).

Building-based aquaponics (BA)

Building-based aquaponics (BA) is a medium-scale infrastructure. The idea behind building-based aquaponics is from the innovative forms of green architecture that aim to combine food, architecture, production and design to produce food on buildings in urban areas (Specht *et al.*, 2014). It may increase food production by exploiting new locations for cultivation. This building-based concept is to integrate food production (fish and vegetable) into existing building infrastructures to save resources and gain high resource efficiency (Specht *et al.*,2014). This also use the combined effort of agricultural production and buildings and create an integrated model within the protected environment of a building (Specht *et al*.,2014).

Table 2.Types of aquaponics system based on media based growing:

Aquaponics Type	Method used	Usage
Deep water culture (DWC) systems	DWC involves plants in Styrofoam sheets that float over grow beds with air supplied.	DWC is the most simple system for large commercial aquaponics growing plants like lettuce, basil, and other leafy plants.
Media-filled bed systems (Flood and Drain Systems)	The media is used in grow beds to support the roots of the plants and for filtration.	These are the most popular design for small-scale aquaponics as they are efficient with space, relatively low cost, and suitable for beginners as they are a very simple in design.
Nutrient film technique (NFT)	NFT uses of plastic pipes laid out horizontally to grow vegetables. Water is lifted from the biofilter into each hydroponic pipe with a small amount of flow creating a shallow stream of nutrient-rich water flowing along the bottom. The pipe contains a number of holes along the top where plants are placed into to grow.	NFT aquaponics shows potential for custom aquaponics designs. While it uses less water than the other two methods. But it is expensive and complicated.

Source: El-Essawy (2018)

On the other hand, aquaponics can be categorized based on farming scale, as follows:

Small-scale Aquaponics

One of the best practices for producing organic food and vegetables at is a small-scale aquaponics system. It is a sustainable technology that requires minimal water and space (Menon *et al*.,2013). A small unit is used here and placed and integrated into the interior design of homes, offices, kitchens, and workspaces.

Low-tech Aquaponics

Aquarium can be transformed easily into an exclusive herb production unit. It demands very low cost and the process requires no special crafts, skills, or tools. Likewise, an aquarium can be prepared from low cost materials with no additional special skills or knowledge is required. It is a fantastic way for the people living in urban to get closer to nature and grow their own fresh herbs, leafy vegetables, and fresh fish protein with less production costs (Nicolae *et al*., 2015).

Micro Aquaponics

An innovative and smart design concept for a micro-scaled aquaponics system paves the way for a new concept of eco-farming systems. The main aim of this system is to use the value of the residue in the water and convert it through a combination of multidisciplinary efforts and thus low environmental impact technologies to become valuable products (Khakyzadeh *et al*., 2015). This requires very small unit. It is portable and sets up based on sustainable farming.To control and remotely monitor aquaponics systems new technologies like wireless sensor is used. These wireless sensors monitor oxygen levels and pH parameters existing in the water. The ammonia levels and water temperature are also monitored in this way. Expert and skilled person needs to monitor and control these parameters. These systems can automatically feed the fish once being programmed in specific times (Guerrero *et al*., 2013). A survey was done to observe the “year respondents started their first aquaponic system” revealed that adoption rate is increasing consequently (Fig. 1).

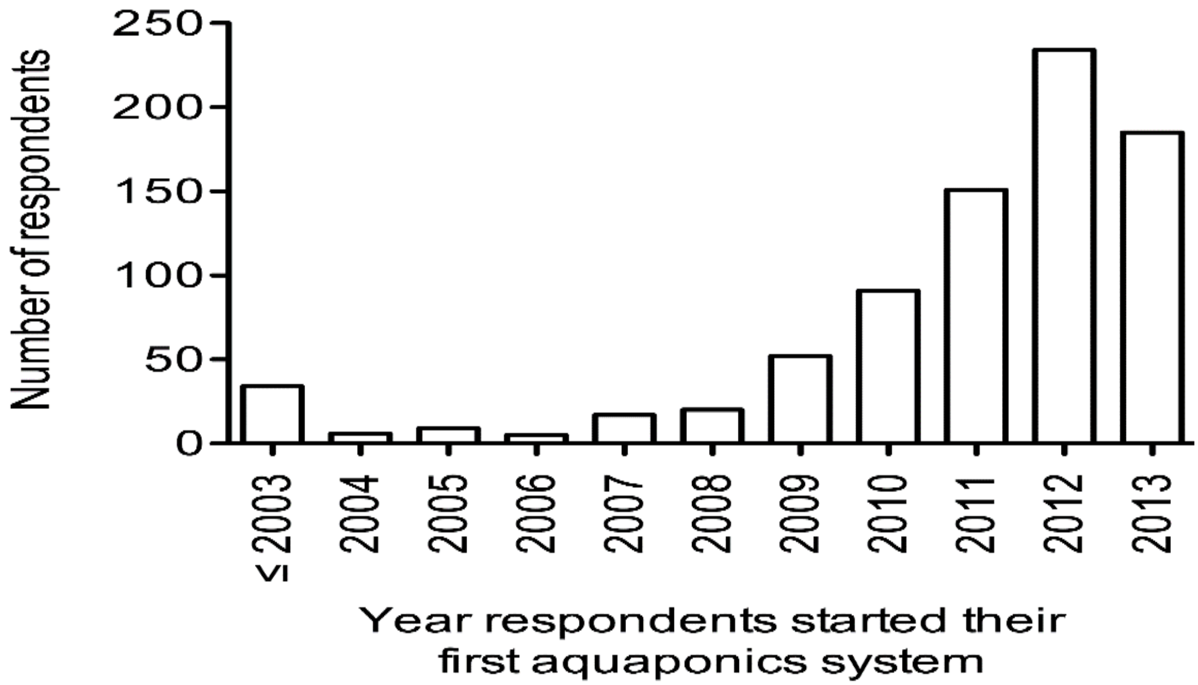

Fig 1: Year respondents and adoption of aquaponic system

Source: Love *et al*. (2014)

Suitable plants for aquaponics

In many commercial aquaponic systems, the hydroponic system gives more production than the aquaculture production. But there are some exceptions, and some farmers earn more from particularly valuable fish farming. A study and survey in the commercial aquaponic units predominantly in the West reveals that up to 90 percent of the financial gains can come from plant production site of aquaponics. A survey found that aquaponics yielded 22.02 kg wet mass (WM)/m2 of lettuce production, or 560% higher than traditional soil crop yield of 3.90 kg WM/m2 where hydroponics had the highest yield of 41.00 kg (WM)/m2(Hollmann,2017).Another survey reveals that ratio of cultivation of herb is comparatively more preferable than other type of plant crops(Fig. 2).In another aquaponic system higher production rate was found in bitter melon(Fig. 3).There is some most popular vegetables to grow in aquaponics like okra, tatsoi, kale, mint, thyme, dill, scallions, chives, cilantro, taro, watercress, salad rocket, edible flowers, even small fruit trees, Root vegetables such as onion, carrot, beets, radish and taro can also be grown. Aquaponics is a novel and alternative method of fish and crop production the combines, a method of growing plant without soil (Aguilara *et al.*,2014).

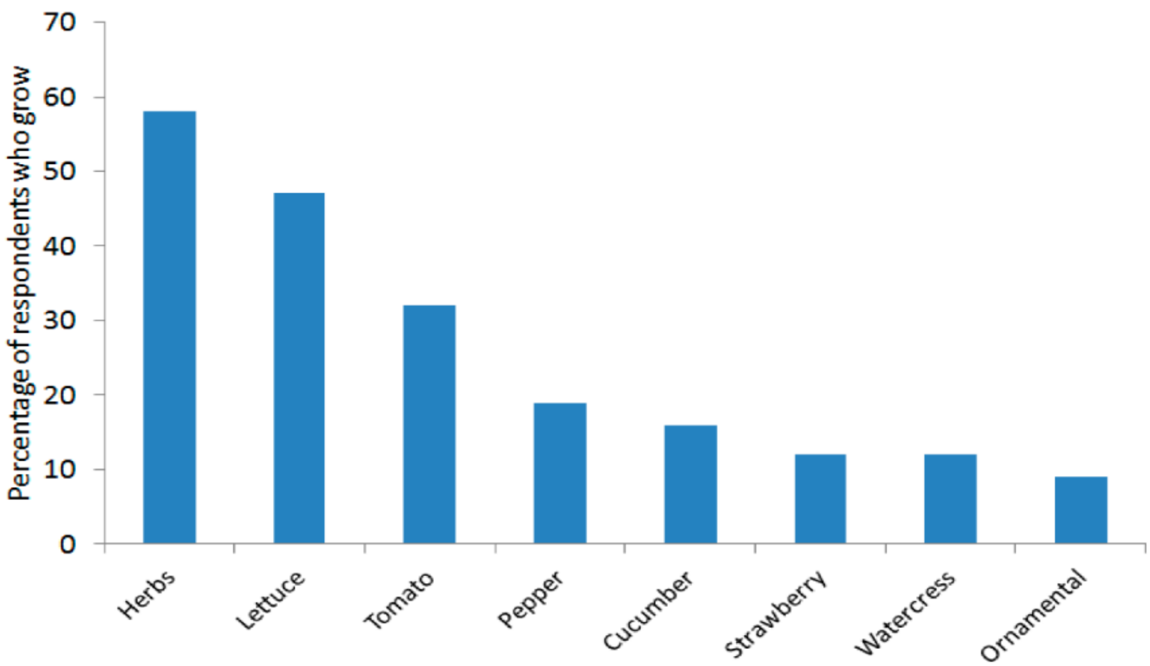

Figure 2: Percentage of respondents that grew the eight most frequent vegetables in the aquaponics

Source: Villarroel *et al*. (2016)

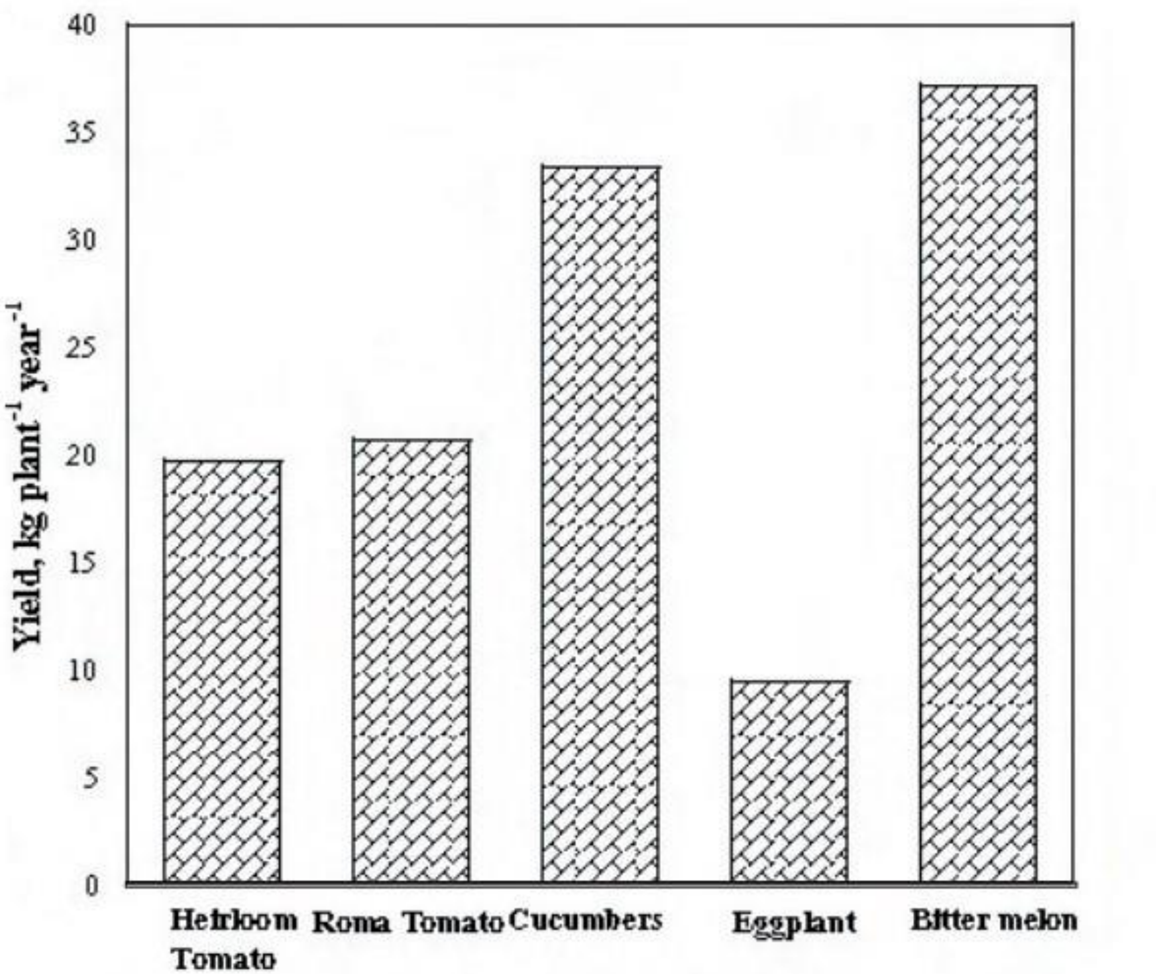

Figure 3: Annual production of vegetable in aquaponics

Source: Savidov *et al*. (2004)

Table 3. Advantages of soil less cultivation in aquaponics over soil based conventional cultivation

Sl no.	Category		Soil-based manual cultivation	Soil less cultivation in aquaponic system
01	**Production**	**Yield**	Very sensitive to soil characteristics, water stress and high dispersal of plants.	Very high with dense crop production.
		Production quality	Products can be of lower quality due to inadequate fertilizer treatment	Full control over delivery of appropriate nutrients at different plant growth stages.
		Sanitation	Risk of contamination due to use of contaminated organic matter as fertilizer.	Minimal risk of contamination for human health.
02	**Nutrition**	**Nutrition delivery**	Difficult to control the levels of nutrients at the root zone.	controlled and homogenous supply of nutrients and pH to the plants at the root zone.
			High nutrient loss due to leaching and runoff.	Minimal amount used. Homogenous distribution and of nutrients. No leaching.
		System efficiency	Very sensitive to soil characteristics, possible water stress in plants, high dispersal of nutrients.	All water loss can be avoided. Supply of water can be fully controlled so no need of labour costs for watering.
03	**Water use**	**salinity**	Susceptible to salt build up, depending on soil and water characteristics. Flushing salt out uses large amounts of water.	Depends on soil and water characteristics.Saline water can be used but needs removal of excess salt.
04	**management**	**Labour and equipment**	Standard, but machines are needed for soil treatment (ploughing) and harvesting which rely on fossil fuels. More manpower needed for operations.	Comparatively a bit costly equipment needed but the benefit is Simpler handling operations for harvest.

Source: Somarville (2014)

Suitable fishes for aquaponics

There is excellent growth rate of some specific fish species in aquaponic units. Fish species preferable for aquaponic farming include: common carp, tilapia, silver carp, grass carp, barramundi, jade perch, catfish, trout, salmon, Murray cod, and largemouth bass. Some of these species, which are available worldwide, grow particularly well in aquaponic units. Aquaponics of Vegetable showed best plant growth combining of Nile tilapia with tomato (Knaus *et al.*,2017). Some cultured fish can be introduced to areas outside of their natural habitat, such as tilapia and a number of carp and catfish species.

Consumers' Willingness to Pay for Aquaponics Products

A survey was made concluding respondents from Europe to measure willingness toward aquaponics products. It was observed that when purchasing vegetables, 17% of respondents would look for aquaponically grown vegetables, 38% of respondents preferred aquaponic fish compared to fish cultivated conventionally, and 23% would choose aquaponic fish even if it cost more. Furthermore, the willingness to pay for aquaponics products in comparison to the other two main premium features of food products, i.e., produced pesticide/herbicide and antibiotic free and produced locally, was also analysed. According to the survey on average, 54% of respondents would be willing to pay more for pesticide/herbicide and antibiotic free products (58% for trout, 52% for tomato and 52% for lettuce), 41% of them was willing to pay more for locally produced products (44% for tomato, 42% for lettuce and 38% for trout) and only 17% of respondents would be willing to pay more for aquaponics products (22% for trout, 15% for tomato and 14% for lettuce) (Fig. 3). It also revealed that how much more in percentage they would be willing to pay for all three types of products, local, pesticide/herbicide and antibiotic free and aquaponics, in comparison to non-local and those produced in traditional farming. On average, respondents would be willing to pay 39.8% more for pesticide and antibiotic free products in comparison to products that are produced in conventional farming, 39.5% more for locally produced products in comparison to products that are not produced locally and 37.6% more for aquaponics products in comparison to those produced in traditional farming. (Miličić *et al.*, 2017).

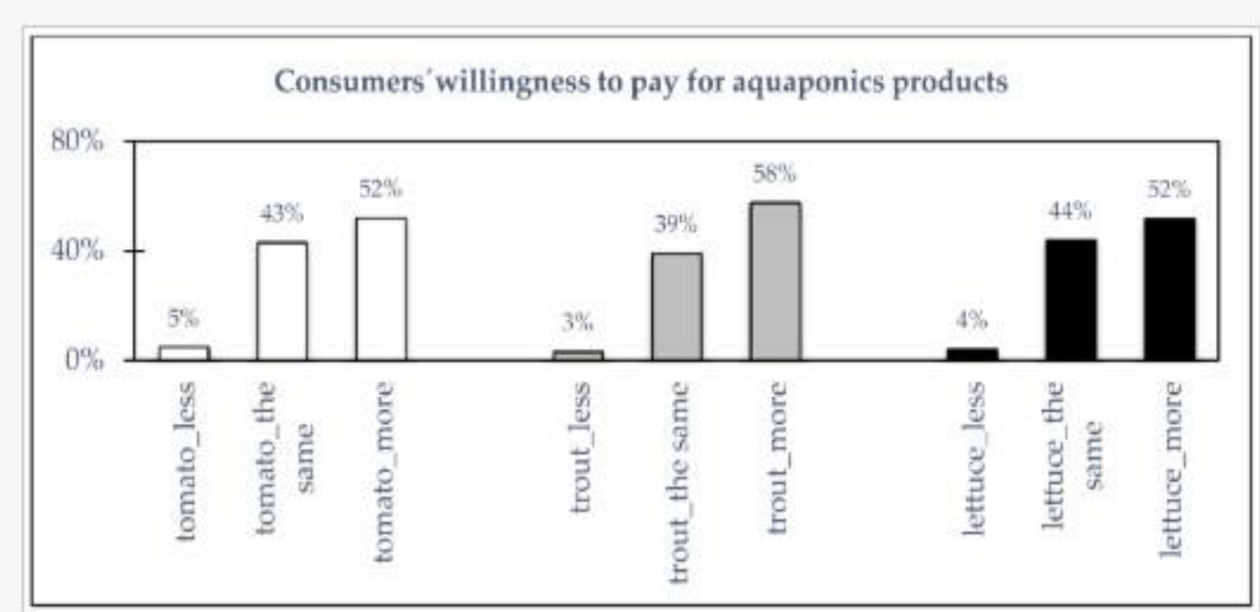

Fig 4: Consumer willingness to pay for aquaponics products

Source: Miličić *et al.* (2017)

Aquaponics is a symbiotic integration of two type of food production disciplines(i) aquaculture the practice of fish farming; and (ii) hydroponics, the cultivation of plants in water without soil(Fig. 4). Aquaponics combines the two within a closed recirculating system (Thorarinsdottir, 2015). An aquaponics system filters the nutrient-rich effluent through an inert substrate containing plants. Bacteria metabolize the fish waste, and plants assimilate the resulting nutrients, with the purified water then returning to the fish tanks (Fig. 5). The hydroponic beds function as a biofilter—stripping off ammonia, nitrates, nitrites through nitrogen cycling and making them available for plant uptake (Fig. 6). The result is the value-added products such as fish and vegetables as well as lower nutrient pollution into watersheds. Aquaponics combines hydroponics and recirculating aquaculture elements. Conventional hydroponics needs mineral fertilizers in order to supply the plants with essential nutrients, but the aquaponics systems use the existing fish water that is rich in fish waste as nutrients for plant growth. Another advantage of this combination is that excess of nutrients does not need to be removed through periodical exchange of enriched fish water with fresh water as practiced in aquaculture systems. The system results in a synergistic effect between fish, microorganisms and plants, and encourages sustainable use of water and nutrients, including their recycling capacity. Within this symbiotic interaction, the respective ecological weaknesses of hydroponics and aquaculture are transformed into strengths. This integration substantially minimizes the cost of input of nutrients and the need for output of waste, unlike when run as seperate systems. (Goddek *et al*., 2015).

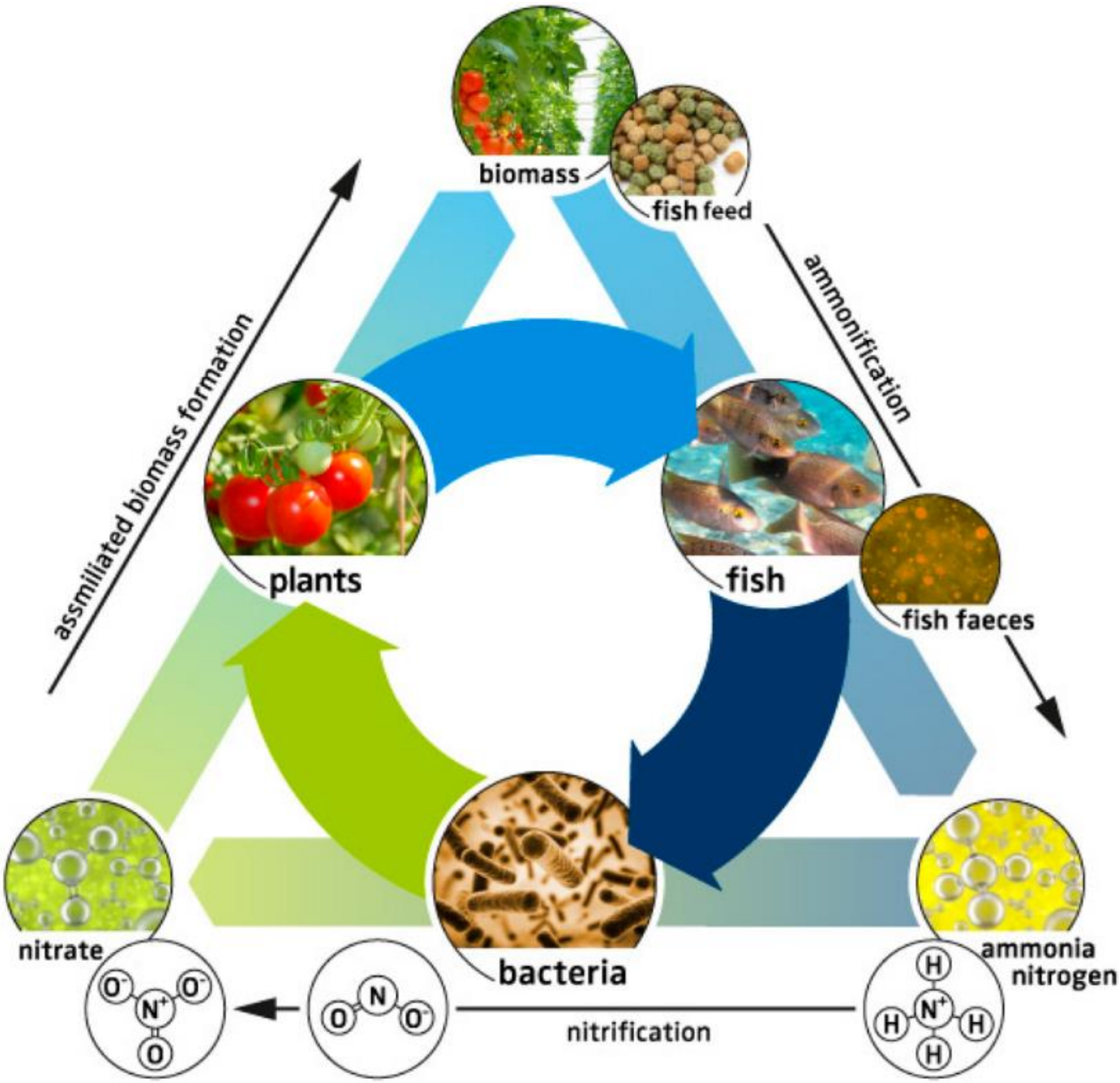

Fig 5: Symbiotic relationship in sustainable aquaponics system

Source: Goddek *et al*. (2015)

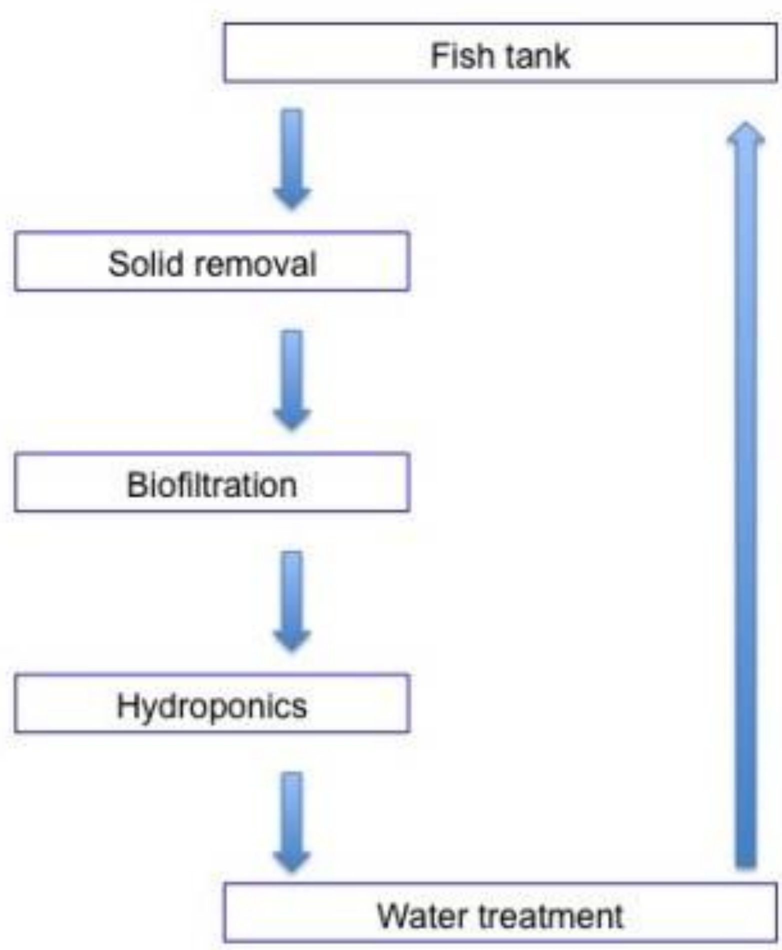

Fig 6: Diagram showing water cycle in sustainable aquaponics system

Source: Lia *et al.* (2018)

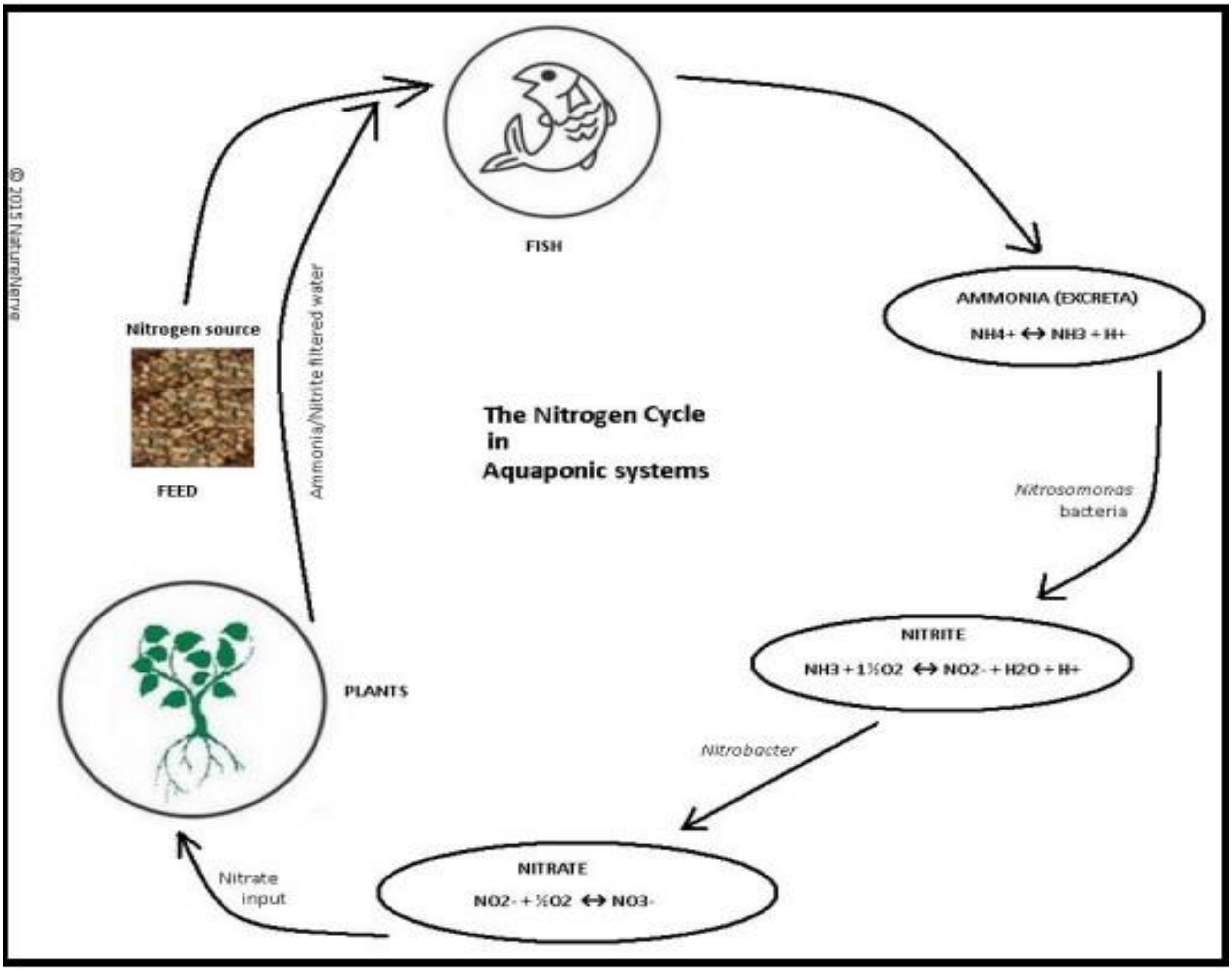

Fig. 7: Nitrogen cycle in sustainable aquaponics system

Source: Asish (2017)

Cultivation Processes of sustainable aquaponics

This system is popularly is an agricultural system where plants and fish are grown and nurture together, instead of a wild and uncultivated environment where things are separated from each other. The individual processes that make up an aquaponics system and enables it to sustain itself are as follows (Fig. 7): waste products of one system supply food or fuel for a second biological system and the combination of fish and plants is a type of polyculture that increases system stability. Biological water filtration removes nutrients from water before it leaves the system (Guerro.,*et al* 2013).

The Ecosystem

An ecosystem is a system that's consists of a community of organisms interacting with their environment. In the case of aquaponics all elements plants, fish, worms and bacteria all work with each other to form an ecosystem.

Recirculation of ecosystem

In this controlled and closed ecosystem, water must be retained and recycled instead of allowing it to drain off or removing it as is again used in hydroponics to meet up the water requirements of the plants. As a result comparatively less water is needed which is good for environment.

Using waste to supply nutrient requirement

The interesting thing about this system is that allows aquaponics to function in a unique way is the nitrifying bacteria that converts the wastes that fishes produce into plants food. Without this transformation process, the fish would simply die by being surrounded in their own waste and the plants would lack nutrients needed to grow.

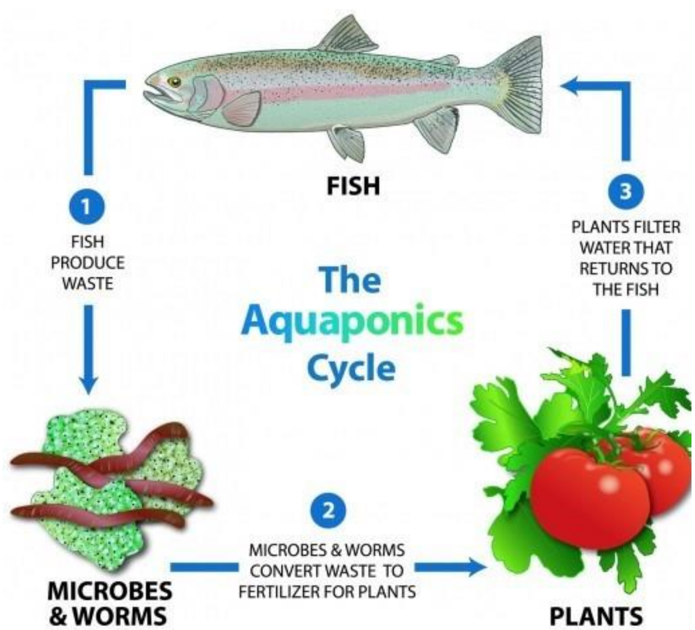

Fig 8: Individual processes in sustainable aquaponic system

Source: Anonymous

3.2 Sustainability of the aquaponics

Sustainability of the aquaponics can be maintained by aquaponics in seven ways. The various ways are presented as follows:

1. Saving water

Undoubtedly water is a precious natural resource. Water quality and water availability are two limiting factors for growing food around the world. Aquaponics requires significantly less water by recirculating it through the fish and plant system. Locations with significant water pollution or contamination should have adequate filtration in place before starting an aquaponic system. But the notable fact that less than 10% of the water used in traditional agriculture is needed which allows that filtered water to grow a lot more in aquaponics than in conventional cultivation. One hundred gallons of water added to an aquaponic system, could be recycled for several days, maybe a week or more. That same amount of water distributed on a conventional method of soil garden would be lost vaporization, leaching or in other ways. There is no pollution of the environment by either fish waste or chemical pollutants (Bernstein,2011).

2. Overcoming the challenges of soil

Aquaponics minimizes the use of soil. Soil has a diverse microbiology and a perfect combination of some types like loam, sand, clay and organic matter. Preparation of soil for cultivation in conventional method usually requires a lot of human efforts like composting, tilling, adding organic material or fertilizer, applying just the right amount of water, in adequate frequency. Aquaponics reduces the cost and efforts for soil management, and that often throws off traditional gardeners. In case of aquaponics it provides the plant everything of its requirement, nutrients, oxygen and water in perfect combination and totally sustainable. So plant roots in aquaponics don't have to bore through the soil to find what it needs and its whole energy can be spend to further development into edible plant material.

3. Growing in places that otherwise don't grow

Aquaponics allows food to be produced in many places that would not otherwise be able to grow Conventional cultivation land is built on a slab of concrete. The soil under that slab is filled with heavy metals and arsenic. The space would not be suitable for growing food unless we were to haul in tons of soil, and then enrich it with nutrients again and again. Concrete, asphalt, sand, clay, rock, or industrial sites may all mean no soil is available to grow in.But these infrastructure can be setup inside greenhouse, warehouse or outdoors where weather is favourable.

4. Natural and constant fertilizer

Aquaponics gets its nutrients from the water source and the byproducts of the fish system, and possibly from the media materials as well. In traditional agriculture often used mined or manufactured chemical and synthetic fertilizers, pesticides and herbicides. These are natural resource intensive to produce, cause significant pollution in the process and don't provide a sustainable model. Since aquaponics creates a natural ecosystem, it is capable enough to supply nutrients that plants need without chemicals. This is helpful to produce good quality of food. It also eliminates labor and time costs for machinery and human resources commonly used to apply chemical fertilizers, herbicides and pesticides are no longer necessary.

5. Producing no waste

Since aquaponics create a natural ecofriendly system there is no formation of waste materials here. Any solids collected from the fish system can be added to compost that support as organic manure for the plants. Any unharvested plant material from the system can also be composted or can be fed to the animals. very little amount of water is needed to be discharged.

6. Reducing "food miles"

Long distance transportation of food makes huge cost for food consumer. Most of the species of tilapia is exported from China, bass from Chile, lettuce, tomatoes and onions from Mexico. Long distance transport for our food means more tine is needed, more refrigeration needed in different locations, more packaging which leads to food safety concerns and less nutritious food since it has left the field many days or weeks before reaching out to the consumer place. Aquaponics allows to produce food in home which ensures nutrition quality since its fresh and much less of all the negatives associated with long distance transportation.

7. Financial sustainability

Aquaponics can be used to improve the livelihoods of households and communities (Konig *et al.*,2016). Unemployed labour gets scope for their employment that means it properly utilizes unemployed labour besides it also ensure proper use of land. waste stream support as total energy supplying backup for the whole system. Aquaponics increase economic efficiency because several key costs, such as nutrients, land and water are substantially reduced and component operating, and infrastructural costs are shared (Bildaru *et al.*,2011). The price of food increasing, and the quality and quantity of the food decreasing and it is found that initial investment of aquaponics well worth its value in nutrition, health, piece of mind, and food security. Aquaponics can be beneficial and good practice for home and hobby scale farming. Farm scale systems can be economically profitable within a very less amount of time if some essential criteria is maintained through like growing the right products, having the right market place, selling at the right price and maintaining costs under control. Thus, financial sustainability is maintained by aquaponics. Financial sustainability is just as important as environmental sustainability. Aquaponics makes as much sense financially by creating natural and symbiotic ecosystem.

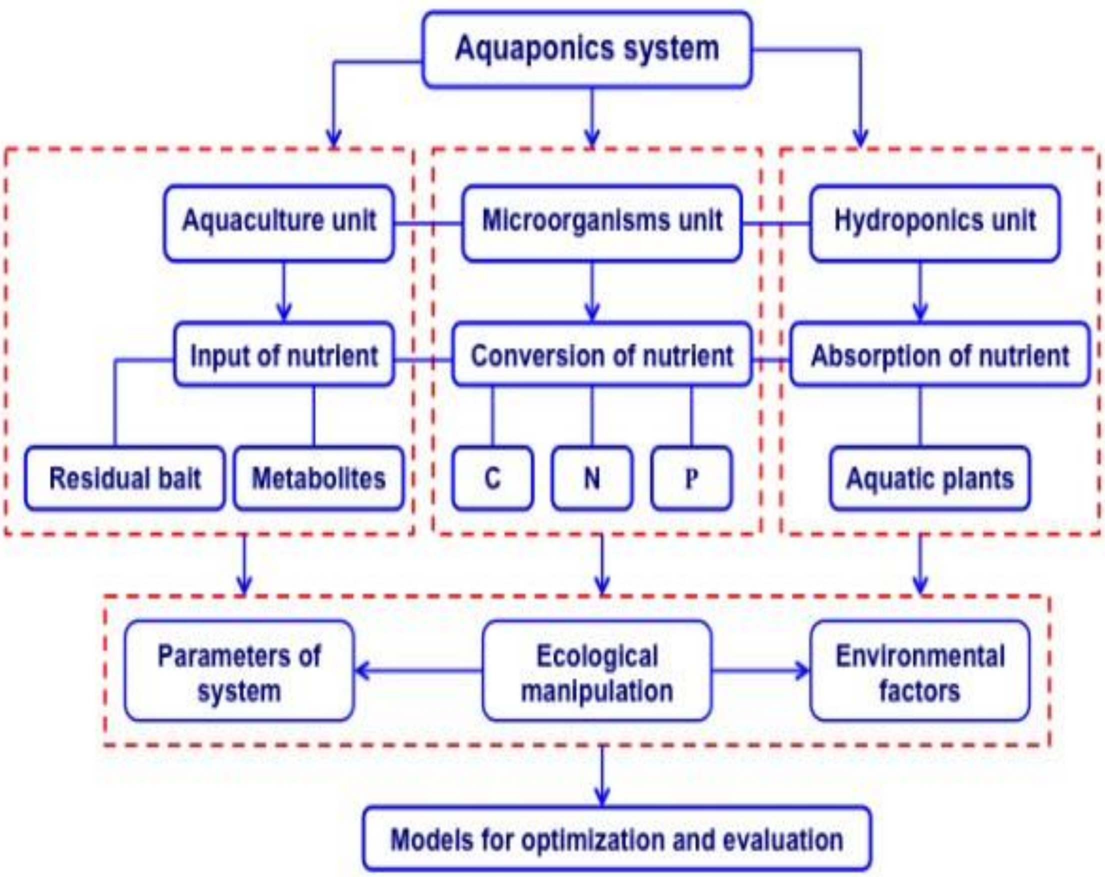

Fig 9: A complete framework for sustainable aquaponic system

Source: Lia *et al*. (2018)

CONCLUSIONS

Aquaponics is a smart and up to date venture towards sustainability, because it makes best outcome from hydroponics and aquaculture. Simultaneously removes the burdens existing in those systems. Its been many years since people started to use aquaponics but no one used words like sustainable. Nowadays more emphasize is given on sustainability. So, the main goal of any innovations or technology is to attain sustainability. Aquaponics seems to be a wonderful option for the future of food growing. It exhibits the prospect for the sustainable development of food production. Essentially food production systems and populations the consumption patterns need to become more sustainable. To address this promising issue and increase the potential to supply fresh food, advanced technologically and integrated systems needed to be explored to ensure a continuity of food supply. In this context Aquaponic projects is successful to play important role towards sustainability.

Besides it saves water, eliminate soil problem and other difficulties faced in traditional cultivation. And thus, the aquaponics system leads to a greater movement towards environmental, social and financial sustainability and which leads to overall sustainability.

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