Sarfraz et al. *LGU. J. Life Sci.* 2020

LGU Journal of
LIFE SCIENCES

LGU Society of
Life Sciences

Review Article
Vol 4 Issue 4 Oct-Dec 2020

LGU J. Life. Sci
ISSN 2519-9404
eISSN 2521-0130

Review on Aquaponics System as A Sustainable Food Production Source

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ABSTRACT: *The global population is growing day by day, so the food demand is escalating as well. Traditional farming practices cannot cater to increasing food demand. Environmental stresses like global warming, mass flooding, insects attack, droughts are some of the key players affecting crop yield. These factors leave the soil barren for cultivation and attaining the highest yield. These changes demand a selection of an alternative method that is not only environment friendly but also sustainable. Aquaponics provides an ideal system for growing plants in soilless conditions. The Aquaponics system is a dual scheme of growing plants and fish at the same time. These systems utilize different approaches for growing plants and fishes simultaneously. This is through by circulating mechanism of an aquaponic system where fish waste in aquaculture provides nutrients to plants for the nourishment of hydroponic units. And plants purify water by utilizing nitrogen to maintain water for fish survival and growth. An aquaponic system is a sustainable methodology that does not affect the environment like conventional farming and is built on the recycling principle. A variety of vegetables like lettuce, cucumber, coriander, spinach, eggplant, basil are popular among domestic aquaponics farmers. Fishes are selected based on features like temperature for growth, nutritional requirements, etc. This review some of the main aquaponics systems and their components. Different requirements for establishing a successful aquaponic system are discussed. Furthermore, the sustainability of the aquaponic system is investigated, as the aquaponics system saves water and delivers nutritious food at smaller and larger scales.*

Keywords: *Aquaponics, sustainable agriculture, tilapia, ecofriendly, water conservation*

INTRODUCTION

The loss of the major agricultural area and overall scarcity of water all around the globe needs a sustainable agricultural system with minimum environmental effects and to meet the food demands of the growing population (Fedoroff et al., 2010). Aquaculture systems enables recirculation of clean water (Adler et al., 2000; Lin et al., 2002). Aquaponics is a bio-integrated system that connects recirculating aquaculture with hydroponics fruits, vegetables, and herb growth (Love et al., 2015). This system has been used for saving water at a same time growing plants in an organic fashion (Lam et al., 2015). The aquaponic system enables the production of fish's biomass in huge quantity. Aquaponics framework generally innovative perfect food production technique reasonable for present and future climate change scenario. The water produced during aquaponic processing contain nutrients, it is used to fertilize and irrigate the growth medium beds (GMB) in hydroponic area in aquaponic system (Rakocy, 2007). As a result, the fish tank gets clean water and plants in return are supplied with various nutrients essential for their growth (Monnet et al., 2002). Hydroponic tank works as a bio-filtration unit, expelling minerals (e.g. ammonia, nitrates, nitrites, and phosphorus, and other trace elements), so, that new clear water then recirculated and return to fish culture (Liang and Chien, 2013).

The nitrifying bacteria present on stones are linked to plant roots which play a major part in the transformation of the nitrogenous compounds (Yildiz et al., 2019). For proper nourishment of fish, the quality of water is important. Generally, fish grown in the recirculating unit needs better quality water than the fish raised naturally. Also, freshwater fishes are greatly affected by the ecological conditions (Fig 1.) (Endut et al., 2010). Improved water quality needs a water testing tools for regular check and balance of an aquaponic system, parameters such as dissolved oxygen needs to be maintained between four to eight milligrams per liter. CO_2, NH_3, NO_3, and NO_2 are required in the system ranges from three to one hundred milligrams per liter. pH, chlorine, and remaining properties needs to regulated as well for proper functioning of the system (Liang and Chien, 2013; Mchunu et al., 2018). continuous and good water monitoring is essential for maintaining stable aquaponic (Fox et al., 2010)

Aqua-farming is a rapidly growing area in the food economy all around the globe, results in a rise of 10% market value annually (Flower et al., 2013). According to one of the reports, the global aquaponics market is progressing at a much faster rate than anticipated due to recent trend of sustainable farming methods. Aquaponics market was 523.7 million U.S. dollars in 2017 and is forecasted to grow to about 870.6 million U.S. dollars by 2022 (Stat, 2017)

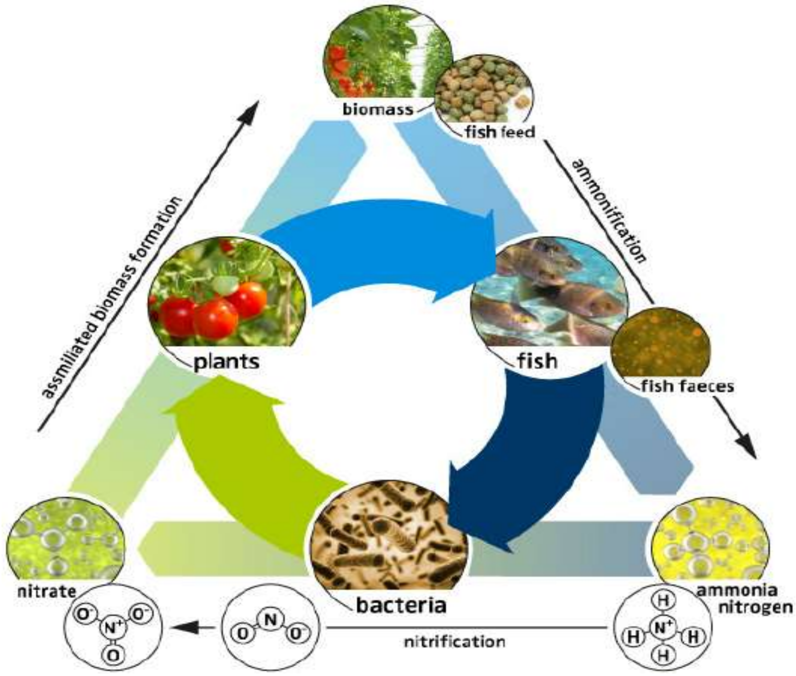


Fig. 1: Aquaponic system symbiotic cycle (Goddek et al., 2015)

Fishes Used in Aquaponics

The ideal fish species in the aquaponic system is Tilapia (Rakocy et al., 2016). The aquaponic system is considered successful with tilapia with proper management (Love et al., 2014). Tilapia is a very important fish species in soil-less farming as it is easily available, cultivable, grows swiftly, considered as disease and stress-resistant, and adapts to wide ranges of the physical environment (El-Sayed and Kawanna, 2004; Hussain, 2004). Due to this ideal condition the tropical, subtropical, and temperate regions are establishing tilapia cultures to lessen the enhanced protein based demand (Ng and Romano, 2013). Fish produces ammonia as an end product, converted by bacteria into the NO_3^- in the upcoming phases (Rakocy et al., 2016). Tilapia species like *Oreochromis niloticus, Oreochromis niloticus x O. aureus, Oreochromis aureus, Oreochromis mossambicus x Oreochromis niloticus, Oreochromis spp.*, are widely used for the aquaponic system Trout, koi, carp, sturgeon are also widely produced through aquaponics. Tilapia is mostly used to grow vegetables like lettuce, cucumber, tomatoes, herbs, and other leafy and fruity vegetables, and has shown maximum performance results (FAO, 2015).

Bacterial Growth in Aquaponics System

Bacteria are essential in the aquaponics unit for the nitrification process. NH_3 is hazardous for fish health especially when ammonia concentrations reach to 0.06 milligram per liter (Reed et al., 2009; Rakocy et al., 2016). In an aquaponic system, the nitrification process releases nutrients plants to abolish NH_3 and form NO_3 from the system (Gutierrez-Wing and Malone, 2006). Bacteria act as biofilters. Two different kinds of bacterial species are involved in this process. First *Nitrobacter*, *Nitrospina*, and *Nitrococcus* oxidizes NH_3 or NH_4 (ammonia) to NO_2 (nitrite) which causes toxicity to fish. The second kind includes *Nitrosomonas* and *Nitrosococcus*, which oxidizes NO_2 into NO_3 (nitrate) (Table 1) (Somerville et al., 2014).

The biofilters in an aquaponic unit are made of gravel, sand, shells, and different types of polyethylene made with increased surface dimension, ideal to form large clusters of nitrifying bacterial species (Rakocy et al., 2006). In this procedure, 93 to 95 percent of ammonia is converted into nitrate as an end product in the filtration tank (Prinsloo et al., 1999).

Table 1: The maximum value of pH for nitrification.

Bacterial species	pH
Nitrosomonas	7.8–8.0
Nitrobacter	7.2–8.2

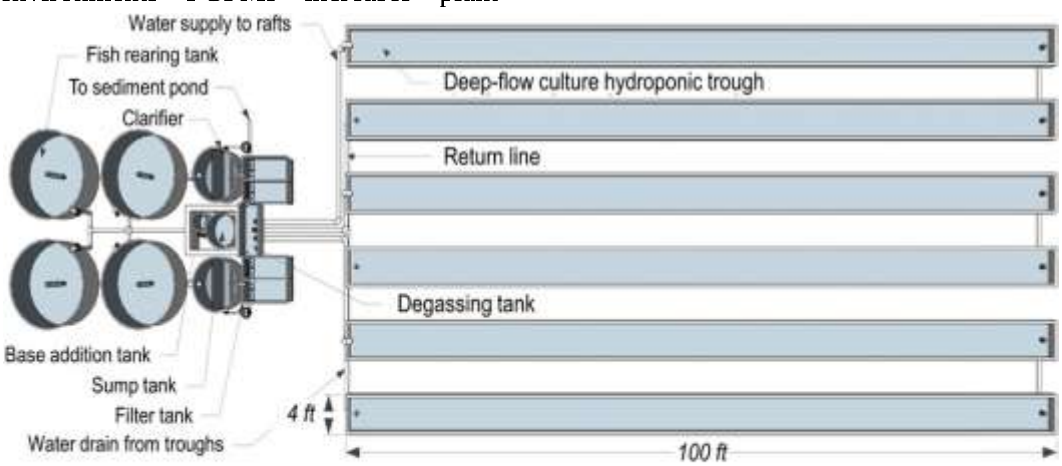
Whereas the maximum temperature value for nitrifying bacteria is between 17–34°C, for dissolved oxygen, it is between four to eight milligrams per liter (Somerville et al., 2014). These requirements are must for the aquaponic system bacterial spp. to function properly. If DO value falls below 2 mg L^{-1}, the nitrification process would be enormously affected. It is essential to manage ideal pH, water temperature, and DO, for working of biofiltration procedure in an aquaponic system (Rakocy et al., 2006).

Nitrification and Denitrification

Maximum nitrification occurs when aeration, water, temperature above 30°C, alkaline pH values conditions occur. (Brummett and Ponzoni, 2009). Whereas, the process ceases at elevated temperature, due to the accessibility of nitrogen as NH_4-N. That causes an exceptional rise in NH_4 volatilization, lessen the nitrification value (Lam et al., 2015). That is a necessarily required factor in the aquaponic system. The ideal temperature ranges from 25°C to 30°C for nitrification, pH requirement is 8.5, the stages vary concerning their tolerance ranges (Liang and Chien, 2013). The nitrification process needs an adequate amount of the oxygen supply, this factor is essential for the management of aquaponics as suspended solids, effluent hinders the working of the aquaponic system (Bene et al., 2015). Limited aeration results in slowing down the speed of the system, whereas increased oxygen supply maximizes the metabolism of bacteria (Fig 2) (Goddek et al., 2015).

Plant growth-promoting microorganisms (PGPMs)

Plant growth microorganism (PGPMs) plays an effective substitute role to chemical addition for the growth of plants. Plants take on the plant growth-promoting microorganisms with a chemical motion from outside of their habitat to their rhizosphere (de Vries and Wallenstein, 2017). Such as phosphorus limiting situation, strigolactone let out in the rhizosphere, works like indicating particle to form a link with fungi (Akiyama et al., 2005). Soil-build environments PGPMs increases plant growth through a different process, such as fixation of nitrogen, decomposition of organic material, root production enhancer, pathogen resistance, and enhancing the bioavailability of bio crystals (Hoflich et al., 1995; Loper and Henkels, 1997; Loper et al., 2012; Malusá et al., 2012; Marasco et al., 2012; Rashid et al., 2012; Mendes et al., 2011; Coleman-Derr and Tringe, 2014; Dias et al., 2015; Pii et al., 2015; da Silva Cerozi and Fitzsimmons, 2016; Khalifa et al., 2016).



Equipment	#	Dimensions	Water volume	Plant growing area
Fish rearing tank	4	10 × 4 ft (D × H)	2060 gal each	---
Cylindro-conical clarifier	2	6 × 4 ft [D × H (3.6-ft-deep cone, 45° slope)]	1000 gal each	---
Filter tank	4	6 × 2.6 × 2.6 ft (L × W × H)	205 gal each	---
Degassing tank	1	5.9 × 2.6 × 2.6 ft (L × W × H)	205 gal	---
Deep-flow culture hydroponic trough	6	100 ft × 4 ft × 16 inches (L × W × H)	2992 gal total	2303 ft² (214.0 m²)
Sump tank	1	4 × 3 ft (D × H)	159 gal	---
Base addition tank	1	2 × 2.6 ft (D × H)	52 gal	---

Fig. 2: Average dimensions and mechanisms of the aquaponic system (Ferrarezi and Bailey, 2019)

Types of Aquaponics

Barrelponics and Duckponics.

Barrelponics and Duckponics system works almost exactly. Both systems have a water pump in their tanks and both pumps are connected to the one power unit, which has a timer. A timer enables the water pump to work for four minutes every four hours. This time constricted pumping action causes all grow beds being flushed with maximum water to fill all pore spaces in the gravel and for some plants water level become higher than gravel and water reaches to some parts of the plant (Yuen, 2014).

Low-Pressure Aeroponics (LPA)

In the LPA system plants grow, while their roots hanging in the air, without the usage of soil. The nutrients are given in the form of mist to the roots of plants. The mist solution is given to plants at low pressure in the huge droplet form, to the roots of plants. The system is quite famous due to its flexible setting and cost-efficient. The homemade LPA system only requires a few PVC pipes and small sprinkler heads (Wainwright et al., 2004).

High-Pressure Aeroponics (HPA)

High-Pressure Aeroponics **(**HPA) growing systems were created by the National Aeronautics and Space Administration (NASA). It has been announced by NASA, high-pressure aeroponics is the most reliable way to develop vegetation in the space. While HPA is a proven good source of growing plants on the earth as well. HPA growing system all are aeroponics but not all aeroponics systems are high pressure. HPA systems need high pressure for working efficiently. The pressure is required to atomize the aqueous solution to fifty microns or below 50 microns to form droplets. Plants are more ready to absorb the nutrient solution. HPA systems are effective and required specific instruments to establish (Gao, 2018).

Fogponics

Fogponics is a sub-branch of aeroponics. It is an indoor gardening method, where plants are hanged in the bound systems without soil or with a specific medium. In fogponic system, the mist of aqueous solution containing nutrient transported into the closed tank by pumping, for the uniform mist enables the root to nourish the plant eventually. Fogponics works on the principle, plant effectively absorbs the particulate nutrient between 1 to 25 micrometer (µm) size range. So, the plant absorbs nutrients better in this form and produces less waste. It is an advanced technique for gardening by using fogponics bucket, crate, and opaque tray utilized to seal in the green roots. It is a sustainable and effective technique to grow fruits, vegetables, and herbs without using soil in indoor conditions. This plant growing system is more reliable than hydroponics mainly because all the water vapor and nutrients remain in the system and not lost in the evaporation process. Plant of tomatoes grows efficiently in fogponics. Fogponics provides uniform distribution and dispersion of nutrients and water equally to all plant roots (Wootton-Beard, 2019).

Marine aquaponics

Freshwater aquaponic is a famous aquaponic technique. The scarce resources of freshwater for agriculture and aquaculture, as soil salinity all around the globe, is increasing (Turcios and Papenbrock, 2014). Opening ways to use brackish water as an alternative resource for agriculture (Pantanella, 2012). The creative plan for the present climate change scenario, aquaculture governs an idea of the formation of "traditional" IAS based on marine water, so halophytes plants may give successful results (Orellana et al., 2014). Many studies present the idea of the waste management of marine aquaculture by using it for the irrigation of the salt-tolerant plant types. (Dufault and Korkmaz, 2000; Dufault et al., 2001; McIntosh and Fitzsimmons, 2003). Marine aquaponics, euryhaline fish species and halophytes plants are mostly grown. (Cataudella et al., 2001).

The halophiles species that are used for the food production are *Chrithmum maritimum* (samphire), *Salsola soda* (agretti), quinoa, and many species of the genus Salicornia (FAO, 2014). Marine aquaponics is also used for the production of horticulture crops such as chard, beet, and many other species of family Chenopodiaceae, by utilizing brackish seawater, salinity level ranges from 3-30 g/L salinity. Up to 1/10 (4 g/L) of sea salinity the species like common tomato, basil, cherry tomatoes produce exceptional growth (Pantanella and Bhujel, 2015). Algae can be grown in high salinity water in the absence of high salinity water as an alternative as well (Pantanella and Bhujel, 2015). Famous species that are used for the production are *Arthospira platensis*, *Arthospira platensis*, and *Porphyra yezoensis*, and *Porphyra tenera*.

Polyconics

The usage of many aquatic organisms in one aquaponic elevated the number of total yields (Naegel, 1977). This is a concept of polyculture in an aquaponic system, in a coupled unit, called 'polyponic'(Knaus and Palm, 2017). Similar to integrated multitrophic aquaculture (IMTA), in polyconics, the diversity of growing food and plants increases which results in the benefits and disadvantages as well. The most grown plants species by polyconic are Chinese cabbage, lettuce, and pakchoi with giant freshwater prawn, and *O. niloticus* (Sace and Fitzsimmons, 2013).

Design approaches used in Aquaponics System

There are three common methods for designing aquaponics i.e. media bed method, deep water culture and nutrient film technique. The nutrient film technique uses the root area contact with the water film that flows while in contact with air and water. Different plants like basil, lettuce, tomato and cucumbers are grown in these channels. The pipes are mostly made up of PVC material. Deepwater Culture or floating raft cultures uses a floating raft to support the plants and their roots which are submerged in the water. This is one of the widely used method trusted by many due to its simplicity, robustness and reliability. Water depth is mostly 4 inches (10 cm) to 3 feet (1 m) or more.

Fishes Integration, Feed Conversion Ratios (FCR) and feed calculations values of Aquaponic System

The quantity of dry feed needed for the nourishment of the 1 kg of wet fish is denoted as feed conversion ratio (FCR) (Nunes et al., 2014). Simply, the total quantity of feed which has the potential for the transformation into a mass of the body, for knowing nutrient release overtime period in an aquaponic system (Nunes et al., 2014). Usually, in low stocking mass, fish placed for 1 kg per 100 L unit equals 10 kg/1000, later this will transform to almost twenty kales in the hydroponic unit for support. Huge fish variety can be cultivated in the well balanced aquaponic system (Lennard, 2004). Recirculating aquaculture systems are ideal for the cultivation of cold and warm water fish species (Allison, 2011). Such as perch, arctic char, catfish, tilapia, bass, and trout (Bene et al., 2015).

For calculation, the feeding is mostly scaled from 51–81 grams of fish food in square meter in 24 hrs. If the vegetation production dimension is 1.127 m^2 in replicate and the complete area will be (3*1.125 m^2). So, the total area for one treatment, required is mostly 3.375 m^2, and the feed value 60 g per day per m^2 (Edaroyati et al., 2017).

The total quantity of food should be in 269-271 grams in a day in 3.377 m^2 of the total dimension of establishing vegetation, fish weight of tilapia in an aquaponic unit eats one to two percent from the total grams of fish body in a day. The average ratio of food for fish, one hundred gram fish, two-gram feed should be given to fish (Edaroyati et al., 2017). Amino acids are the essential component for fish food, as a building block of fish structure and essential for the metabolism, and also plays a little role in energy conservation (Bahnasawy, 2009).

Modeling Requirements of Aquaponics

The real system simple representation is called modeling, for aquaponic, system needs an absolute knowledge for different system workings (Janse, 1997). In an aquaponic unit, different processes like nutrient flow, nitrogen mineralization, fish, and plant ecosystem are used (Mazzotti and Vinci, 2007). The aquaponic system can be complicated mainly due to the inability of expertise and complete understanding of fish and crop requirements in the agricultural system.

Efficient working of the Aquaponics System

The balanced nutrient, control of flow in the aquaponic system is determined by FCR, plays a crucial role in the management of the system. The identification of the FCR, two models are currently in use. The first one was formed by Rakocy et al. (2016). The nutrient movement technique of aquaponic was formed by the research of more than twenty years by Rakocy (Hu et al., 2015). The studies concluded that a huge amount of nitrogen and phosphorous are produced by fish which are essential for the nourishment of the plants. Whereas, fish needs different nutrients for different plants. Like, the dung production of fish will eventually not help the full life cycle of cultivated plants, so that's why there will be requirements of various supplements and trace elements. The least amount of nutrients that are required for fish food are named as, calcium, potassium, and iron but the same trace nutrient are essential for the proper nourishment of plants. Another model was proposed by Lennard's, the model predicted the nutrient transformation of *Maccullochella peelii* for the hydroponic yield of vegetables (Lennard, 2004). The two modeling methods are acknowledged by both scientists.

Sustainability Concept of Aquaponic System

Sustainability is a capacity to conserve structure at a balanced rate (Olukunle, 2014). Sustainability is a condition of not damaging the surroundings or reducing innate assets and, thus keep up the long-term ecological, social, economic equilibrium (Bockstaller et al., 2009).

Environmental Sustainability of Aquaponics

Aquaponics offers many advantages to the environment, like the practice of ecologically sound setup and urban landscapes, decreases transport emissions, utilization of used and recycled water, energy consumption and growth, organic waste recycling, latest landscape opportunities at the same time. Few restrictions for the environmental effects that could be occurred in the future like technical advancement, inability to deal with complexity, and favoritism in the agricultural system. Few studies results showed, a small level of the aquaponic system is more reliable and are more sustainable than the larger system because the widespread system required more fuel, management, etc. These systems reduced water purity and may show a role in habitat fragmentation. The initial capital investment of aquaponics is typically required a huge sum, that's why they are somehow not ideal for the developing countries where mostly the framer are poor (Specht et al., 2014).

Economic Sustainability of Aquaponics

As in the conventional farming market, the rates fluctuate on the daily basis based on the demand and supply statistics, which need qualified profitable proficiency (Goddek et al., 2015). Therefore, to achieve economic sustainability, the sound skills of experts is needed to earn a subsidy from the aquaponic system.

Economic sustainability can be achieved through the following guidelines such as; (1) grade of revenues and application should be growing and preserved as needed, with excellent deliberation in terms of social and geographically adequate placement, (2) economic range and confrontation for latest techniques must be upgraded, (3) public sector should manage urgently with sustainability principle e.g. conservation of departments, land, etc. to achieve capital based on high yield, associated with social and human capital, should be conserved to indicate qualitative advancement, market tools like pricing should be considered fundamentals of economic factors (Mchunu et al., 2017). The suitable fish feed according to the type of fish and climate of that area is a critical affair as it is the prime ingredient of the aquaponic system.

Social Sustainability of Aquaponics

An important attempt in about conservation and sustainability, in terms of agriculture, depends upon the environmental viewpoint for the management of issues (Brummett and Ponzoni, 2009).

For the aquaponic system, skill depends upon the scale of the system (Love et al., 2015). Social sustainability is a critical asset as it is necessary for the making good changes in people's life. The rules that support the social sustainability to assess and escort different social problem for attaining sustainability, such as, to understand the social sustainability, following principle should be known that is, (a) protection and well-being of humans should be induced and preserve thoroughly, (b) teaching and training should be given, entitle reorganization and growth, (c) traditional setting should be encouraged with the introduction of new and feasible social standards and products for economic growth, (d) protection of rights and law for man and women equally (e) unity encouragement in the generations all around the globe and locally as well (Mchunu et al., 2017). The aquaponic system represents the sustainable ecological model (Rakocy, 2007; Palm et al., 2014). Another mechanism to evaluate aquaponic sustainability can be done with energy, as the energy software model provides the assessment of the agriculture system. As, all around the globe youth is seem less interested in the agricultural system (Faber et al., 2011).

Food Security and Aquaponics

Food security, when every individual, all the time have nutritious, clean and enough food supply in access, enables daily requirement and choice of diet for well-being (Allison, 2011). The four pier which describes the food security are availability, accessibility, utilization and stability of food (Drangert, 1998). Availability fulfilled healthy food accessibility all times for common people. Accessibility is accomplished with uninterrupted food availability along economic capability. Utilization is fulfilled food that is digested by the humans and enable the healthy life, and, stability fulfilled when these piers are accomplished (Faber et al., 2011). Above all this, nutrition security is a new plan that is a concept for poor people, for the realization of food security.

To deal with these pillars, aquaponic system governs an exceptionally good idea for the concurrent growth of fish and greens, enables food sovereignty for food security, where aquaponics system working for community and controls the production they gain. As, fish is an important nutritious protein source (FAO, 2015). As necessary proteins are often not present in vegetables kind of diet (FAO, 2014). To increase food, water and nutritious security, aquaponic systems are advised to install at household level at small scale (Faber et al., 2011). A successful aquaponics system requires operations with some general and computer skills at smaller scale, whereas, the producer needs to manage the production and marketing of meat and green at the same time (Xiang et al., 2004; Rakocy, 2007).

Limitations and Future Scope of Aquaponics System

In the current climate change scenario where the exhaustion of natural resources a big threat to all living organisms. The application of fertilizers in the agricultural governs land, air, and water pollution lands along with the water scarcity issue, aquaponic system is a sustainable way to produce meat and green with reuse of water. The system is not supported by common farmer due to high initial setup cost, few vegetable growing capacity, technical requirement, filtration problems, suitable conditions requirement.

These limitations can be overcome by increasing the knowledge of the future climate change impacts to common farmers in monetary terms. The technical problems can be solved using simple software like dropdown list, visual basic application, solver drop down list etc. for less educated farmers may be supported by government programme. For entrepreneur (educated farmer) software like; C++, Mat lab, Python etc. halt the technical problems. The genetic engineering incorporation is needed for healthy and maximum yield, more research is required for the production of number of vegetables and fish species, and enable them to adapt different environmental conditions. In case of emergency condition when the excessive growth of algae needed to be dealt the biosynthesized nanoparticles can be used with some advancement for the cleaning purposes.

CONCLUSION

Aquaponics is approach where hydroponic and aquaculture systems combines, so the nutrient containing water passed to the hydroponic system for the production of vegetables and fish. Gradual shifting in the climatic change scenario stresses on the traditional agricultural practices as these practices requires a substantial sum of water, numerous kinds of fertilizers, mechanical tools and tight monitoring. This approach is more sustainable approach for the production of green and meat. This system does not need heavy fertilizers, pesticides, or herbicides. Also, the system utilizes less than 90% water than conventional agriculture practices. Additionally, the aquaponics system can produce food six times more per square foot than systematic soil farming. It is chiefly an environment-friendly method. Recirculating systems aquaponics culture and marine culture can provide substantial yields of both fishes as well as the plants, which would not only be an efficient way of utilizing water but also providing fishes their natural habitat. The establishment of the aquaponic system is ideal for the local farmer to help the economy with little effects on the environment.

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