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Review on Aquaponics System for Fish Farming

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Abstract: Human population grows with rapid urbanization that results a shortage of land for production of feed for the growing population. Due to this world wide problem different production methods are emerged. Like, Aquaponics which is the integration of aquaculture and hydroponics in one recirculating system. Aquaculture is the production of aquatic organisms under controlled conditions while hydroponics is the production of vegetables without soil. The integration of the two systems helps to use limited water and land resources. Due to huge demand on water resources and subsequently food supply new trends of agricultural production system have been practiced. Rakocy was the first person to develop a fully-functional aquaponics system having aquaculture, fish tank, hydroponics, bacteria and fish waste as main components. Depend on the methods of production system aquaponics divided into floating raft, nutrient film technique and media bed system. To perform aquaponics production there are some important water parameter which must be fulfill such as; pH, dissolved oxygen, electrical conductivity and temperature. In aquaponics unit the nutrient rich effluent from the fish tank is filtered through an inert substrate in the hydroponic bed containing plants that function as a bio-filter by stripping off ammonia, nitrates, nitrites and phosphorus so that fresh and clean water can be recirculate back into the fish tank; concurrently used to avoid pollution. Aquaponics systems are promising for implementation in arid and semi-arid areas that lack adequate water and land for conventional agriculture. But there are some problem related to management and knowledge. As aquaponics farming is still in its infancy in Ethiopia it is interesting to know about the aquaponics production system and share the experience for fish farmers.

Key words: Aquaculture · Aquaponocs · Fish · Hydroponics · Less Resource · Pollution

INTRODUCTION

Aquaponics system is suitable for sustainable environmental ethics and responsible use of earth resources which attract attention all over the world as human population grows with rapid urbanization. As recent in 2015, the United Nations (UN) projected that the world population will increase by more than one billion people within the next 15 years, reaching 8.5 billion in 2030 and a greater majority of those people (66%) are predicted to live in cities by the year 2050. When viewed from the perspective of food systems in our contemporary society, the current evidence available on a worldwide unsustainable system cannot be ignored, which raises questions on how the present and future challenges ought to be addressed [1, 2]. China and the Gulf States are already looking at purchasing land in other countries in order to feed their own populations. Aquaponics is now considered as one of the future production approach that focus on improving productivity and performance because, it offer opportunities for innovation and production in environments where agriculture would not be traditionally possible [3].

Aquaponics systems combine the two forms of agricultural production:- recirculating aquaculture and hydroponics. Aquaponics provides a solution to the main issues these two systems face; the need for sustainable ways of filtering or disposing of nutrient-rich fish waste in aquaculture and the need for nutrient-rich water to act as a fertilizer with all of the nutrients and minerals needed for plants grown through hydroponics [4]. Today, modern aquaponics is a viable resource to sustainability that combines aquaculture (growing fish and plants in a controlled environment) and hydroponics (growing plants

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without soil). The system relies on fish waste to provide organic food and nutrients as the plants clean, filter and recycle the water back to the fish creating a symbiotic relationship [5].

Aquaponics is suitable for environments with limited land and water because it produces about three to six times the vegetables and uses about 1% of the freshwater used by traditional aquaculture [6]. Efficient and effective water management in agriculture will generate the income for improved rural livelihood; it is only under such conditions that the development of health, education and protection of the environment will be ensured sustainably [7]. In future agriculture demands will lead to increase forest conversions, natural resource degradation and environmental pollution as traditional farming was unsustain the demand for the growing population. Innovating new sustainable agriculture practices will be essential to offset the escalating food crises and environmental degradation in a sustainable manner [8].

The government model related to natural resources has to be change as there is need to expand small farmers and landless peasants' access to productive assets in countries of the lands, water sources and fisheries. There should be a shift away from the prevailing model of concentration of land in small groups of big land owners who are dropping food production for local markets and moving to big industrial production of commodities that produce no local benefits [9]. Several problems of the environmental type are known to arise from aquaculture system like discharge pollution that leads to eutrophication, habitat modification and chemical pollution from antibiotics, pesticides and the depletion of fish due to fishing to provide fish feed ingredients [10].

Thus, the objective of this seminar paper is to highlight on:

Aquaponics as integrated fish and plant production system to feed rapidly increasing world population without pollution and less resource in all year round.

Definition and History of Aquaponics

Definition of Aquaponics: Aquaponics is defined as an integrated multi-trophic food production system comprising a recirculating aquaculture system (RAS) and a hydroponic unit, the plants and fish are cultured together in a mutually beneficial series. Waste produced by the fish contains lots of beneficial nutrient sources (e.g. phosphorus and ammonia) which are harmful to the fish if they remain in water in great quantities. However, these wastes through the action of nitrifying microbes (e.g. the genus Nitrosomonas and nitrobacteria) make good liquid fertilizer constituents that are taken-up by the plants in the process purifying the water [11].

The primary resources used in animal or crop production are water, nutrients, light and land. Intensive RAS can produce more fish per liter of water than other types of aquaculture systems [12]. In aquaponics system the recovery of dissolved nutrients by the plants can contribute in reduction of environmental impacts of fish effluents; minimize water exchange in fish production and operational costs [13].

History of Aquaponics: [14] Published the first description of an aquaponics system, which diverted aquaculture effluent through plant growing troughs. The concept was that the nutrients in aquaculture effluent could be put to good use to nourish and grow plants; meanwhile, potentially polluted fish water would be cleaned up before being released into the environment.

Rakocy, Hargreaves and Bailey [18] Reviewed on aquaponics and concluded that estimates of nutrient uptake and a deeper understanding of culture water nutrient dynamics are a necessity in the development of criteria for designing aquaponics systems.

Components of Aquaponic System

Aquaculture: The UN-FAO defines aquaculture as the farming of aquatic organisms including fish, mollusks, crustaceans and aquatic plants. Farming here implies some form of intervention either by individuals or corporate ownership of the stock being cultivated in the rearing process to enhance production such as regular stocking, feeding and protection from predators [19].

Aquaculture is the science, art and business of aquatic organism production due to a decreasing supply of wild catfish species, the demand for fish culture is increasing; thus make aquaculture the fastest growing sector of agriculture [21]. Tilapia is the fourth most consumed aquaculture product in the world followed by Catfish and Salmon [22].

Hydroponics: In hydroponics it is possible to provide essential nutrients that the plant needs in correct ratio and produce plants which are stress free, fast growers and better quality [24]. It is a way of food production system in which nutrient solutions are added to the water and provide dissolved minerals for the growth of plants in the absence of soil [25].

Most popular vegetable to grow in aquaponics systems are leafy vegetables and herbs especially lettuce and basil. These systems are generally less suitable for fruit vegetables because of the longer production cycle and preference for different nutrient ratios. Fruit vegetables typically have higher nutrient demand and may need different nutrient levels at different stages of growth. They are therefore more difficult to grow successfully in aquaponics systems. Basil and tomato have a higher nitrogen content than lettuce or coriander and the balance between fish feeding and plant density may need to be adjusted accordingly [26]. Crops can also grow in a concentrated manner without compromising the health of the system and while greatly reducing the required input of water resources [4] and increasing the value gained from the continuously cleaned and recycled water [27].

Tilapia Feed: Fish in aquaculture require less food than wild fish as they need less energy to survive and obtain food, thus the controlled use of fish feed pellets gives the grower complete control of the nutrient inputs into the aquaponics system [28].

Fish Tank: Dirty water is pumped from the tank to the bath tub which contains potted plants including tomatoes and basil. The plants utilize the fish excreta as nutrients and the clean water which is then recycled and pumped into the fish tank [29].

Bacteria: The conversion of ammonia into nitrates is one of the most important functions in an aquaponics system as it reduces the toxicity of the water for fish and allows the resulting nitrate compounds to be removed by the plants for nourishment is called nitrification. Ammonia is steadily released into the water through the excreta and gills of fish as a product of their metabolism but, must be filtered out of the water since higher concentrations of ammonia commonly between 0.5 and 1 ppm can kill fish. Although plants can absorb ammonia from the water to some degree nitrates are assimilated more easily [30]. Ammonia can be converted into other nitrogenous compounds through healthy populations of; Nitrosomonas:- (bacteria that convert ammonia into nitrites) and Nitrobacteria:- (bacteria that convert nitrites into nitrates) [31].

Types of Aquaponic System: Common aquaponic applications of hydroponic systems include: Recirculating aquaponics, solid media such as gravel or clay beads held in a container that is flooded with water from the aquaculture [32].

Floating Raft System: Plants were grown in water on floating polystyrene sheets called rafts which require aeration of the water to provide oxygen to plant roots and to support nitrification. The raft system is also called deep water culture of aquaponics and used in small to large scale productions. In this system plants grow on the styrofoam which can float on top of the water. The plant root is grown directly in to the oxygenated culture water. Water from the fish tank flows to bio-filter and then to grow beds in which the plants are grown. Then clean water flows back to the fish tank [33].

Fig. 1: Raft system of aquaponics (Source: [10].

Media Filled Bed System: The media beds must be made of a strong inert material have a depth of about 30 cm which filled with media containing a high surface area to provide adequate mechanical and biological filtration that separate zones for different organisms to grow and be sufficiently wetted through flooding and draining or other irrigation techniques to ensure filtration [10]. Media based recirculating aquaponics have solid media such as gravel or clay beads held in a container that is flooded with water from the aquaculture and also called flood-and-drain aquaponics or ebb-and-flow aquaponics [34].

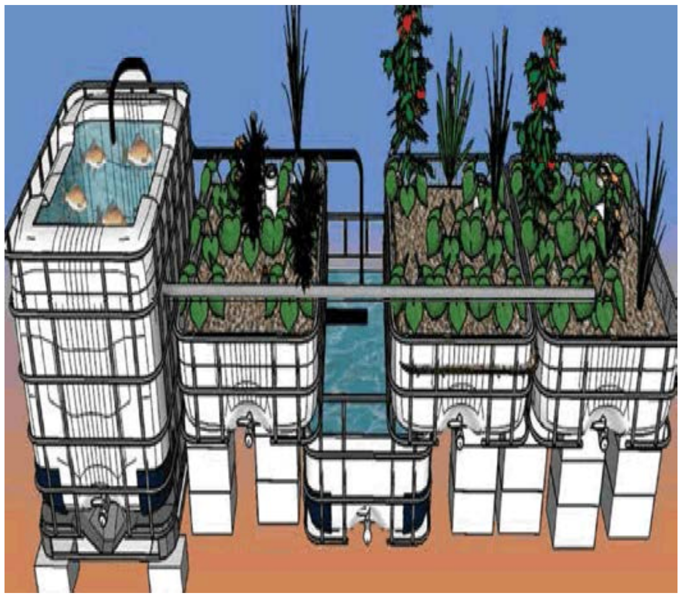

Fig. 2: Media bed system (Source: [10].

Nutrient Film Technique (NFT): System in which plant root were held out of the water and exposed to moist air called nutrient film technique. Which consists of the plant root being exposed to a thin layer of nutrient water runs through pipe most often a Polyvinyl Chloride (PVC) pipe. The idea is that the shallow flow of water only reaches the bottom of the thick layer of roots that develops in the trough while the top of the root mass is exposed to the air to receive an adequate oxygen supply [35]. Channel slope, length and flow rate must be calculated to make sure that plants receive sufficient water, oxygen and nutrients. If properly constructed NFT can sustain very high plant densities will produce. In aquaponics NFT systems the bio-filter becomes crucial as there is no large surface area whereby bacteria communities can develop [4].

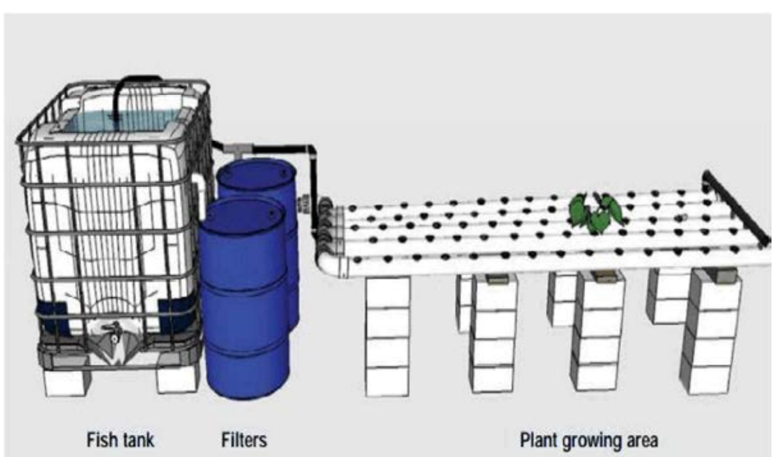

Fig. 3: Nutrient film techniques (Source: [10].

Water Quality Parametres of Aquaponics: Good water quality must be maintained at all times in a recirculating fish tank to maintain optimal growth conditions and health of the fish. Thus, the most important water quality parameters are temperature [36]; dissolved oxygen ammonia, salinity, chlorine and carbon dioxide [37]. Optimal water quality is essential to a healthy, balanced and functioning aquaculture system [38]. Factors that affect the quality of fish tank water include the stocking density of the fish, growth rate, feeding rate, volume of water in the system and environmental conditions [30].

pH: Fish can tolerate a fairly wide range of pH, but do best at levels of 6.5-8.5. Substantial changes in pH is 0.3 within a period of 12-24 hours can be problematic or even lethal for fish. Therefore, it is important to keep the pH as stable as possible. Buffering with carbonate is recommended to prevent large pH swings [10].

Dissolved Oxygen (DO): A clear sign for lack of oxygen are gasping for air at the surface. This behavior is called piping, in which the fish swim close to the surface of the water and take air into their mouths. This is an emergency situation that needs immediate attention of aeration [39]. For aquaponic systems in general, a DO level of 80% saturation (6-7 mg/L) is optimal [4].

Electrical Conductivity: Electrical conductivity is an indicator of the concentration of the nutrients available in a solution and it is measured by electrical conductivity. The recommended level of electrical conductivity in hydroponics for production of most plants is 1500-2500 μS/cm [40].

Temperature: In aquaponics, tilapia are usually raised between 22.2 and 23.3°C in order that the needs of the fish, the nitrifying bacteria and the aquaponic plants are met as plants perform better at slightly lower temperatures [4].

How Aquaponic Works?: In an aquaponics unit the nutrient rich effluent from the fish tank is filtered through an inert substrate in the hydroponic bed containing plants that help function as a bio-filter by stripping off ammonia, nitrates, nitrites and phosphorus so that freshly cleansed water can be recirculate back into the fish tanks [19].

Nitrifying bacteria like genus Nitrosomonas that are Ammonia-oxidizing bacteria (AOB) consumes ammonia (NH_3) and convert to nitrite (NO_2-) and the genus Nitrobacteria which is, Nitrite-oxidizing bacteria (NOB) consume nitrite (NO_2-) and convert into nitrate (NO_3-) in which the plants use to grow. Therefore, the bacteria help in nutrient cycling by metabolizing the fish waste and the process is called nitrification. The hydroponically grown plants assimilate the resulting nutrients as liquid fertilizer [41]. The hydroponic bed and its crop serve as a bio-filter for the fish waste before the water is returned back into the fish tank. Then the waste of one biological system becomes nutrients for another biological system [30].

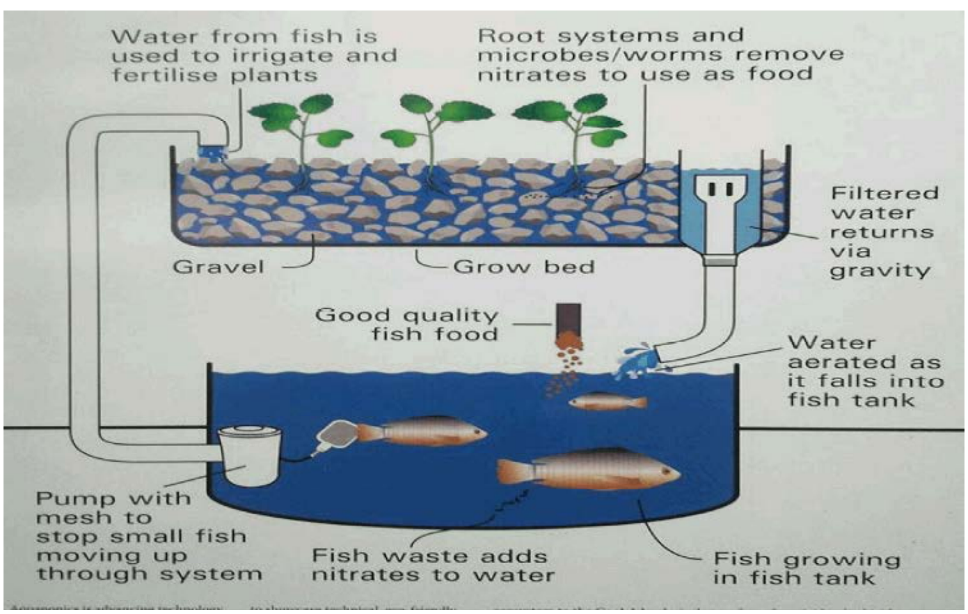

Fig. 4: Simple small-scale aquaponic systems (Source: [26].

Advantage and Disadvantage of Aquaponics and Traditional Fish Farming: Conventional agricultural or geoponic practices can cause a wide range of negative impacts on the environment. This defined as the practice of growing crops in soil, open air, with irrigation and the active application of nutrients [42].

Why Aquaponics Better than Traditional Farming?: Aquaponics systems are seen promising for implementation in arid and semi-arid areas that lack adequate water and land for conventional agriculture [43]. Aquaponics is a great sustainable option for food production for the current age and future. In an aquaponics system you have the option to use beautiful tilapia or koi fish to suit your vegetarian or vegan lifestyle. Having an aquaponics garden is very therapeutic, relaxing and fun for children. Aquaponics uses only a fraction of the water used in conventional farming and aquaculture which is why it's the farming of the future Aquaponics is for everybody [44].

Advantage of Aquponics: Aquaponics shares many of the advantages than hydroponics and conventional production methods including reduced land area requirements, reduced water consumption, accelerated plant growth rates and all year-round production in controlled environments [45]. It is an extremely resource efficient and sustainable method of producing crops on any scale that imitates the plant-fish interactions found in a natural waterway [46].

Aquaponics system can provide food year-round even during the dry season in arid regions where water and soil resources may be scarce and can act as the key to self-sustenance for communities living in developing regions of the world and normally depending on world food markets [47]. The lack of a need for soil in these systems implies that they can be used in urban regions and in places with poor soil quality [4]. Aquaponics uses 90% less water than conventional crop farming and has the ability to increase yield eight to ten times compared to conventional agriculture [48].

Increasing health consciousness and world demands for fish supplies require a solution such as aquaponics which can provide an answer to the greater picture with increased resource-efficiency and at a lower cost [49]. Aquaponics does not require the addition of synthetic chemical fertilizer as the fish waste from the rearing tank provides adequate amounts of the essential ammonia, nitrate, nitrite, phosphorus, potassium and micronutrients as well as some secondary nutrients for the healthy growth of hydroponic plants [30].

The use of synthetic herbicides and pesticides is also unnecessary and would greatly compromise the health of the fish that are highly sensitive to water quality [4].

Disadvantages of Aquaponics: There are a few disadvantages with aquaponic systems. First the ratio of hydroponic growing area compared to fish rearing surface area is relatively large. Another disadvantage includes the labor involved with plant management. The majority of aqua culturists do not have horticulture experience. Furthermore, due to the close relationship between fish and plants within an aquaponic system, poor management practices can easily affect the sensitive system. Pesticides cannot be utilized within systems and thus, biological control or natural methods must be used to eliminate plant pests [21].

Lastly, materials utilized for aquaponic production such as clay, fish feed and tank are not considered sustainable. These materials utilize nonrenewable resources for production [50]. Hydroponic disadvantages may include high capital costs for construction, incidences of root disease and introduction of soil borne diseases, quick plant reaction to nutrient element insufficiencies [51] and anoxic conditions that may impede ion uptake [52].

Aquaponics and Fish Farming in Ethiopia: Aquaponics is the integration of recirculating aquaculture and hydroponics into one production system. The system is based on the principle where two ecosystems are synergizing to produce products that are not independently obtainable. The fish in the aquaponics system provide the plants nutrients to grow. Then plants act as bio-filter to clean the water that is necessary for the fish to survive [55].

High quality fish feed is needed for systems in order to run effective. However, quality fish feed is expensive and not available in many developing countries. Especially in Africa, where fish feed is difficult to get for small-scale farmers due to underdeveloped infrastructure and industry [56]. Aquaponics is an interesting alternative compared to conventional agriculture, as aquaponics has the ability to reduce pressure on water and land projects have been starting up in Ethiopia. However, one of the current difficulties of aquaponic systems in Ethiopia is the lack of quality fish-feed as an input for the aquaponic systems [57].

As aquaponics reduce the water and land use, it is possible that more water and land resources become available. This extra water and land availability can be used for expansion of farms in conventional agriculture.

If strict regulations would be put in place it is possible to use aquaponics as a conservation tool to protect natural resources. Unfortunately, it has to be noted that within the current situation in Ethiopia it will be difficult to implement strict regulations [58].

The use of small-scale aquaponic set-ups in developing countries with a small land property try to find alternative farming practices for food production [59]. For example; the average size of land property of aquaponic farmers in Hawassa is 0.44ha and for Shoa-Robit this is 0.33ha. When this is compared with the land size of conventional farmers, it shows that the average land property of conventional farmers is larger. The average size of the land property in Hawassa is 0.55ha and in Shoa-Robit a land size of 0.7ha This shows that aquaponic farmers have in average less land size compared to conventional farmers [60].

As aquaponic farming is still in its infancy in Ethiopia it is interesting to know if the new aquaponic farmers have farm experience before the farmers initiated with aquaponic farming [61]. In developing countries, one of the biggest constraints to tilapia nutritionists is preparation of commercial cost effective feed by using locally available resources [62]. Similarly in Ethiopia commercial fish feeds are not readily available and unaffordable to farmers for fish culture [63].

CONCLUSION

In future agricultural demands will lead to increase deforestation, natural resource degradation and environmental pollution. Some of the negative impacts of traditional agriculture and aquaculture include the high and improper use of water and land, wastage of resource and soil degradation. As traditional farming cannot sustain the demand for the growing population, searching new sustainable agricultural practices will be essential to solve the increasing food crises and environmental degradation in a sustainable manner. The rapid growth of the world population should consider with rate of feed production using appropriate method. Thus, Aquaponics can contribute to solve food security concerns as it cannot be achieve by only simple mass production.

Based on the above conclusion the following recommendations are forwarded;

- Government model related to natural resources has to be changed to aquaponics system and should give appropriate training on the management of aquaponics production system.
- As aquaponics production system need less resource it should be practice in urban area, less fertile soil and dry season to provide food all-year-round.
- Aquaponics production system should be practiced in order to eliminate environmental pollution and global warming.

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List of Abbreviations:

AOB	Ammonia Oxidizing Bacteria
CSA	Central Statistical Agency
DO	Dissolved Oxygen
FAO	Food and Agricultural Organization
Ha	Hectare
NFT	Nutrient Film Technique
NH_3	Ammonia
NO^-_3	Nitrate
NO^-_2	Nitrite
NOB	Nitrite-Oxidizing Bacteria
pH	Potential of Hydrogen
PVC	Polyvinyl Chloride
RAS	Recirculating Aquaculture System
UN	United Nation
UNDP	United Nation Development Program
UNFAO	United Nation Food and Agricultural Organization
µS/ cm	Micro-Siemens per Centimeter
UVI	University of the Virgin Islands

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