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Aquaponics: An innovative approach of symbiotic farming

Panigrahi G.K.[1*], Sasmita Panda[2] and Surendra Nath Padhi[3]
[1]Division of Biosciences and Bio-informatics, RNA Genomics LAB, Myongji University, South-Korea.
[2]Lecturer in Zoology, Jatni College-Jatni, Khurda-752050, Odisha, India.
[3]Zoology Reader Emeritus, Jayanti Kutira, Jatni, Odisha, India.

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Abstract: Aquaponics is a typical bio-integrated system that forms a critical link between the recirculating aquaculture with hydroponic vegetable, flower, and/or herb production. It establishes a type of symbiotic relationship between aquatic animals with that of plants with in a system. Recent advances by researchers all around the globe have curved aquaponics into a working model of sustainable food production. This innovation named aquaponics respects principle of sustainability as well as gives a possibility to increase economical efficiency with an additional productivity. For the improvement of man's health, we must reconsider the agricultural sciences in such a way that we can develop technologies friendly for the environment.

Key words: Aquaponics; Hydroponics; Farming; Agriculture; Technology; Environment; Sustainable; Aquaculture

Introduction

Aquaponics is the merger of aquaculture or fish cultivation and hydroponics or plant farming devoid of soil. The escalating rate of scientific and technological innovation has kept researchers in an unremitting struggle to update themselves with the latest codes of practices, technologies and scientific breakthroughs. The need and exigency of sustainable development for the aquaculture is beyond the thought. Increased productivity with reduced ecological impact, integration between production systems and reduced use of chemicals are some of the leading principles that more sustainable fish production needs to follow Diver, (2006). The safety of food for human consumption is alarming on a worldwide level. Aquaculture represents fish farming, one system where commercial fishes are reared in containers, ponds or tanks. Hydroponics generally refers to the production of plants without soil. Plant roots are able to grow in a nutrient solution with or without an artificial medium for mechanical support Pantanella, (2008). Hydroponics is one of the plant culture techniques, which enables plant growth in a nutrient media with the mechanical support of inert substrata. Hydroponics is considered as a promising technique not only for plant physiology experiments but also for commercial production Hutchinson, (2004).

Both aquaculture and hydroponics have some negative aspects. Hydroponics requires costly nutrients to feed the plants, and also periodic flushing of the systems is required which leads to waste disposal issues. Aquaculture needs to have excess nutrients removed from the system; normally this means that some amount of the water is removed, generally on a daily basis. This nutrient rich water needs to be disposed off regularly and replaced with clean fresh water. While aquaculture and hydroponics are both very efficient methods of producing fish and vegetables, when we look at combining these two, these negative aspects are curved into positives.

Fish produces mainly nitrogenous wastes. If these wastes accumulate, it can be fatal for the life of fish, but if they can be managed efficiently then the same waste can be a great fertilizer for plants. As the plants take up these nutrients, they purify the water, which is beneficial for the fish. Many cultures have been made using this cycle to grow better crops and rear the fish as an additional food source. This simple logic is the base for Aquaponics culture. Rice paddies in the China and Thailand and many other countries across the globe have been using aquaponics technique for years. The Aztecs developed a system of building floating islands for food-plants such as maize and squash. Fish use to propagate around the islands, leaving their waste on the lake bottom, where it could be collected to fertilize the plants.

Modern aquaponics is slightly more technically efficient which makes use of environment friendly approach to produce food. Fish are usually kept in large tanks and the plants are grown hydroponically; that is, without soil. Plants are mainly planted in beds with a little gravel or clay and their roots hang down into the water. The water is cycled through the system, so that it collects the "waste" from the fish and recirculates back to the plant beds, where it is naturally filtered by the plants and then again returned to the fish

***Corresponding Author:**
Panigrahi G.K.,
Division of Biosciences and Bio-informatics,
RNA Genomics LAB,
Myongji University, South Korea.
E-mail: gagan.rie@gmail.com

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tanks. In this trend of culture, no chemical fertilizers are needed for the plants unlike traditional farming methods as in the present context they all come from the fish-waste. It also tends to be organic, because the use of pesticides would be detrimental to the fish.

Thus, aquaponics is a sustainable system that combines both hydroponic (plant) and aquaculture (animal) systems. This system makes use of the natural biological cycles (Nitrification). It allows us to produce fish and plants in a single system with a large reduction in water use (Fig.1)

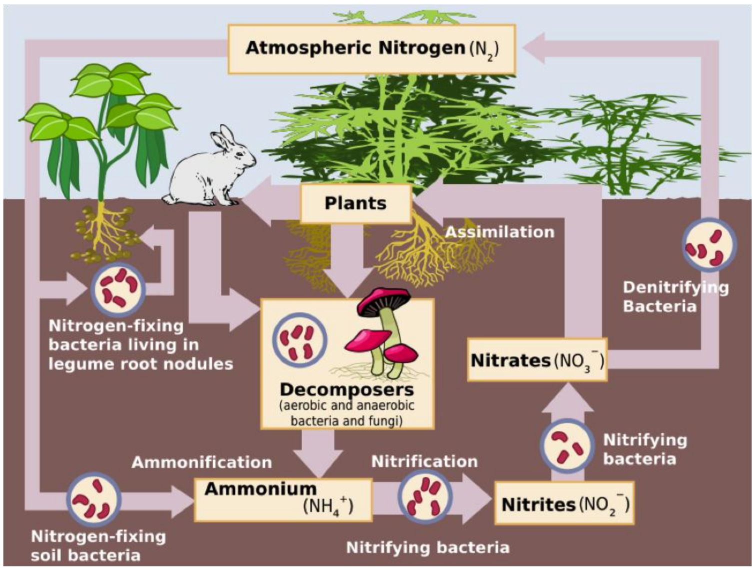

Figure 1: Aquaponics basic diagram

Why aquaponics

Aquaponics as an integrated system helps to negotiate many of the crises prevailing across the globe. Some of the common crises are increasing population, food shortages, increasing unemployment, global warming, etc. This system only uses a fraction of the water, about 10% of soil growing. There is no need to purchase, store and apply fertilizer, no soil-borne diseases, no tilling, and no weeds. It results in high fish stocking density, high crop yield. This integrated system relies on the principle of no waste as waste from fish is been used by plants. In other words waste from fish is used to feed the plants. Water is re-used in the re-circulating system. No pesticides or herbicides required rather continuous organic fertilizer is supplied naturally. This system aids to food security as we can grow our own food within a defined space, year-round and equally potent in draught or places with poor soil quality which results in local food production, enhances the local economy and reduces food transportation. Thus, aquaponics is considered as sustainable as it has lots of advantages with respect to hydroponics and aquaculture (Table 1) along with a cutting edge for meeting several crises.

Table1: Comparison between hydroponics, aquaculture and aquaponics.

System	Advantages	Disadvantages
Hydroponics	Produces a high volume of crops in a small space The most water efficient method of crop production	Dependent on manufactured fertilizers that are costly
Aquaculture	Produce a large volume of fish in a small space	It has a high rate of failure due to high stocking rates Fish produce ammonia, algae, minerals that are to be constantly filtered
Aquaponics	No pesticide, thereby reducing carbon footprint The plants get an automatic food supply from the fish water The plants filter the water for the fish	Management requires skills in growing fish and plants

How Aquaponics Works (Fig. 2)

Fish are raised in a tank

⇩

Water from the fish tank is pumped to the plants

⇩

Plants absorb the nutrient rich water

⇩

Bacteria convert ammonia and nitrite to nitrate

⇩

Filtered water is returned to the fish tank

⇩

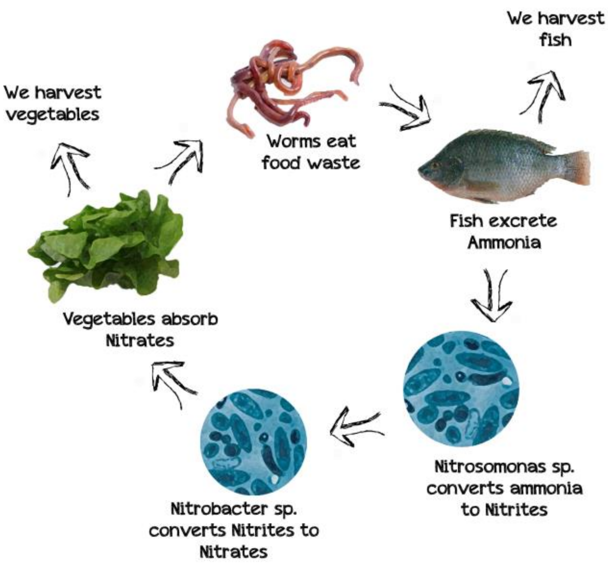

Figure 2: Diagram illustrating general working of Aquaponics

Components

Aquaponics is comprised of two main parts, aquaculture part for raising aquatic animals and the hydroponics part for growing plants Rakocy and Diver, (2006). Although consisting primarily of these two parts, aquaponics systems are usually categorized into several components or subsystems responsible for the effective removal of solid wastes, for adding bases to neutralize acids, or for maintaining water oxygenation Rakocy, (2006).

Typical components include:

- Fish Tank
- Place to Grow Plants
- Water Pump(s)
- Air Pump
- Irrigation Tubing
- Water Heater (Optional)
- Filtration (Optional)
- Grow light (Optional)
- Fish and Plants
- Sump
- Settling basin

Fish tank is used to rear fish. Water pumps and air pump are used to regulate the water level and air level respectively. Irrigation tubing is well connected throughout, so that it creates a re-circulating system. Sump is the lowest point in the system where the water flows to and from which it is pumped back to the fish tanks. Settling basin is a unit for catching uneaten food and detached biofilms, and for settling out fine particulates (Fig. 3)

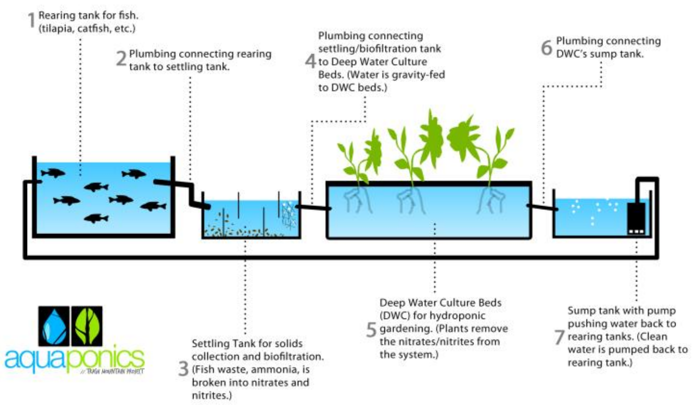

Figure 3: General setup of an aquaponics system

Plants: hydroponics

Plants are grown as in hydroponics systems, with their roots immersed in the nutrient-rich effluent water. This enables them to filter out the ammonia that is toxic to the aquatic animals, or its metabolites. After the water has passed through the hydroponic subsystem, it is cleaned and oxygenated, and can return to the aquaculture vessels. This cycle is continuous. Without plants the system cannot function properly. Growing plants in soil is fairly easy but takes up valuable space because of moisture and spacing requirements.

Aquaponics takes care of this automatically, without much thought except to insure the flow of water. If the electricity quits or a pump fails the plants will survive several days up to two weeks depending on the temperature, but of course the fish will die within hours. Even plants needing large amounts of nitrogen, like tomatoes, can exist side by side with plants that require little, like lettuce. The nutrient rich water reaches all plants and because it only passes through, only what is needed is used. Even with good plant coverage there are a lot of nitrates flowing out the drains back to the fish tank, enough in fact to power up another group of grow beds. This is not a concern unless the water is cloudy in the fish tank.

Vegetables like Lettuce, Beans, Squash, Zucchini, Broccoli, Peppers, Cucumbers, Peas, Spinach, etc. Herbs like Basil, Thyme, Cilantro, Sage, Lemongrass, Wheatgrass, Oregano, Parsley, etc. Fruits like Strawberries, Watermelon, Cantaloupe, Tomatoes, etc. Most garden varieties flowers can also be grown.

Why do Plants like Aquaponics

- Nutrients constantly provided
- Warm water bathing the roots
- Don't have to search for water or food
- Less effort needed in putting out roots
- All the energy goes into growing UP not DOWN
- No weed competition

All of the above mentioned factors aids all the necessary ingredients responsible for a better and healthy growth of the plants.

What influences the amount of available nutrients to plants

Many factors as mentioned below held responsible for the availability of nutrients to the plants. These factors should be tightly and timely regulated for the optimum growth of the plants.

- Density of fish population
- Size of fish
- Temperature of water
- Amount of uneaten fish feed in water
- Availability of beneficial bacteria
- Amount of plants in the system
- Media present in system
- Water flow rate

Economical rising effectiveness with vegetables production

Aquaponics presents an promising opportunity to rethink the traditional fish farming, to fetch in more money at the farm gate. Two profit centers for producers: fish and plants. If fish goes through a stumpy cycle then we have plant revenue to rely on and vice versa. Many experts claim that aquaponics has the potential to produce more than conventional or hydroponics where as some claim it produces considerably less. The integration of fish and plants is a kind of polyculture that increases diversity and thereby enhances system stability. Aquaponics increase economical efficiency because several key costs such as nutrients, land and water are substantially reduced and module operating and infrastructural costs are shared.

The system involves no control of root pathogens, as these are controlled biologically by the broad spectrum of antagonistic micro-organisms that develop in the natural environment Nichols, (2008). Aquaponics is a bio-integrated system that associates recirculating aquaculture with hydroponic vegetable, flower, or herb production

Gordon and Chalmers, (2004). This production type of fish and vegetables, is right where the market is headed- consumers are demanding safe food produced in an environmentally responsible way. The fact that aquaponic products are locally produced, and therefore, "leaving a small foot print on earth, is an added bonus". Terms such as "natural", "environmentally friendly", "pesticide free", "organic" have growing attraction to consumers Graham, (2003).

Aquaponics process, gives big advantages in earlier and faster plant crop production to capture more profits. This type of agriculture might mean a stepped-up investment, but it is one that creates another revenue stream (from fish) linked with more profitable plant production. Some benefits of this system outlined by Amadis, (2010):

- Faster growth rate, crop maturity and yields
- Consistency and quality of crops
- Drastically reduced water and nutrients compared with soil-grown produce
- Crops can be grown in places where ordinary horticulture and aquaculture is impossible due to poor or contaminated soil or water
- Reduced growing area required
- Systems can be set up at a comfortable working height, excellent for people who are elderly or have disabilities
- Relative freedom from soil diseases and pests
- Weeds are virtually non-existent
- Water stress is reduced in hot conditions
- Less ongoing maintenance required

Increasing economical efficiency of aquaculture by aquaponics, is given from the fact that by this innovation water consume is reduced to minimum and most important we obtain organic vegetable products, that means an additional product which brings to us extra cash.

Animals: aquaculture

Aquariums require filtering systems that must be either cleaned or replaced on a regular basis. The grow beds of the aquaponics system by themselves act as this filter without the hassle of cleaning or replacing. Of course, plants must be present in the grow beds. Almost many freshwater fish can be raised in the system although the operating temperature may prohibit rearing of some species such as trout. Freshwater fish are the most common aquatic animal raised using aquaponics, Fish like aquarium fish, Tilapia, Trout, Catfish, Yellow Perch, Bass, Bluegill, Carp, Koi, Goldfish, freshwater Prawns are recommended for rearing in an aquaponic system.

Fish Maintenance

- Feed fish 2 - 3 times a day, but shouldn't be overfed
- Fish eat 1.5 – 2% their body weight per day, this should be taken care of
- Fish should be fed only that which they can eat in 5-10 minutes
- Fish won't eat if they are too cold, too hot or stressed, thus temperature conditions should be well regulated
- Water quality should be checked periodically
- Fish behavior and appearance should be observed

Fish Health Management

- Good hygiene and bio security—prevention, avoidance, selective access, and commonsense should always be exercised.
- Before stocking fish from other facilities into own's system it should be quarantined properly. Their health should be monitored for several days—treat if necessary.
- The best defense is fish's own immune system. Always there should be a low-stress environment so that fish will maintain their health.

Bacteria

Nitrification which involves the aerobic conversion of ammonia into nitrates, is one of the most important functions in an aquaponics system as it helps in reducing the toxicity of the water for fish, and thus allows the resulting nitrate compounds to be removed by the plants for nourishment Rakocy, (2006). 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 as higher concentration is detrimental to fish. Although plants can absorb ammonia from the water to some degree, nitrates are assimilated more easily thereby efficiently reducing the toxicity of the water for fish Rakocy, (2006). Ammonia can be converted into other nitrogenous compounds through:

- *Nitrosomonas*: bacteria that convert ammonia into nitrites, and
- *Nitrobacter*: bacteria that convert nitrites into nitrates.

In an aquaponics system, the bacteria responsible for this process form a biofilm on all solid surfaces throughout the system that are in constant contact with the water. The submerged roots of the vegetables combined have a large surface area, so that many bacteria can accumulate there. Care for these bacterial colonies is important as to regulate the full assimilation of ammonia and nitrite. This is why most aquaponics systems include a bio filtering unit, which helps facilitate growth of these micro organisms. Since the nitrification process acidifies the water, non-sodium bases such as potassium hydroxide or calcium hydroxide can be added for neutralizing the water's pH. In addition, selected minerals or nutrients such as iron can be added in addition to the fish waste that serves as the main source of nutrients to plants Rakocy, (2006). A good way to deal with solids buildup in aquaponics is the use of worms, which liquefy the solid organic matter so that it can be utilized by the plants and/or animals.

Technical Operation

Ten key guiding principles for creating successful aquaponics systems were issued by Dr. James Rakocy, the director of the aquaponics research team at the University of The Virgin Islands, based on extensive research done as part of the *Agricultural Experiment Station* aquaculture program:

- Use a feeding rate ratio for design calculations
- Keep feed input relatively constant
- Supplement with calcium, potassium and iron
- Ensure good aeration
- Remove solids
- Be careful with aggregates
- Oversize pipes
- Use biological pest control
- Ensure adequate bio filtration
- Control pH

The vital inputs to the system are water, oxygen, light, feed given to the aquatic animals, etc. In terms of output, an aquaponics system may frequently yield plants such as vegetables grown in hydroponics, and edible aquatic species raised in an aquaculture. Typical build ratios are .5 to 1 square foot of grow space for every 3.8 L of aquaculture water in the system. 3.8 L of water can support between 0.23 kg and 0.45 kg of fish stock depending on aeration and filtration. Target pH should be maintained between7.0–8.0. A thorough knowledge of the organisms in the system is required for success. pH, ammonia, dissolved Oxygen, soluble Salts, alkalinity, nitrate are some of the measures for water quality which should be monitored periodically.

Safe Materials

All the components used in the system should be made sure that they are safe for fish and humans:

- Polypropylene - labeled PP
- High Density Polyethylene - labeled HDPE
- High Impact ABS (Hydroponic Grow Trays)
- Stainless Steel barrels
- EPDM or PVC (poly vinyl chloride) pond liner (make sure its UV resistant and avoid fire retardant material)
- Fibreglass tanks and grow beds
- Rigid white PVC pipe and fittings, black flexible PVC tubing, some ABS
- DO NOT use Copper – Its toxic to the fish

System Maintenance

- Fish should be fed daily and their health should be monitored regularly.
- Water quality should be tested (every other day for the first month, then about once a week, then as needed).
- Filter screens, filter tanks (if using), tubing, water pump, grow bed media etc. should be cleaned out as and when needed.
- Plant health should be checked.
- Plants should be checked for bugs or nutrient deficiencies in a regular fashion.

System Start-up Checklist

- Type and size of system to build should be clearly decided
- Drawing to be done for designs, research where to get parts, plan
- Components should be brought and assembled properly
- Plants should be grown from seed or some source for seedlings should be found
- System should be filled with water and circulated (at least a week)
- About 20% of stocking density of fish should be added to the system
- Water quality should be monitored and partial water changes should be done as and when needed
- System should be maintained properly

Handy Tips and Tricks

- Gravel media should be washed before putting into the system – otherwise it will lead to very cloudy dirty water
- pH of the gravel media should be tested
- Vitamin C and an air pump to bubble out chlorine and chloramines from tap water should be used
- Worms (red wigglers) need to be used in media beds to breakdown solids and reduce anaerobic zones
- Cleaning products, pesticides, algaecides, fertilizers or like substances shouldn't be used in fish tanks or grow beds
- Plants should be sprayed with diluted vinegar and water solution if aphides infect the plants
- Direct sunlight on fish tanks should be avoided, the top should be covered to avoid algae and make fish happy
- More than 1/3 of water at a time shouldn't be changed. More than that will destroy the good bacteria in the system.
- Outdoor plants should be covered during a frost, and shade from the scorching summer sun. We need to make sure that we have backup power available for pumps and aerators

Benefits from Aquaponics

- **Addresses issues on food safety**
  - Produce do not contain the most common pathogen
- **Maximizes the use of space**
  - Diversified operations (fish and plants)
  - Ability to produce a large quantity of food in a small space
  - No land is needed
- **Ease of operation**
  - No weeding
  - No soil cultivation
  - Minimal watering
  - No pesticide application
  - Minimal maintenance and time spent
- **Addresses issues on climate change**

- Conserves water
- No leaching of nutrients or waste to be pumped into the environment

- **A great educational tool to teach children grow food and care for living things**
- **Operation is friendly to persons with physical disability**
- **Products are higher in nutrient and better**

Future perspectives

Simplicity in design and management with almost no energy and low equipment costs makes these systems an interesting solution wherever land availability, flooding, productivity and ecological footprint are a major issue. In addition the employ of water weeds as a resource can certainly increase livelihoods opportunities in all those areas affected worldwide. Further research needs to address the nutrient dynamics of different growing media and to optimize system design and nutritional requirement of vegetables in those water bodies with limited dissolved nutrients. The possibilities of this integrated system are quite high and can provide sensitive benefits to smallholders as well as big aquaculture enterprises. The potential of these systems is however not fully understood and interdisciplinary links and research can unquestionably address many of the issues that are still hidden.

Conclusion

Aquaponics is the combination of aquaculture and hydroponic systems whereby nutrient rich waste water from the aquaculture system is engaged into the hydroponic system. The trends of new millennium in environmental regulation, are limiting amount of water which may be consumed or discharged. In aquaponics, wastewater from aquaculture is filtered and is recirculated into the system. Aquaponics presents an opportunity to rethink the traditional fish farming, to bring in more money farm gate.

"The ultimate goal of farming is not the growing of crops, but the cultivation and perfection of human beings." — Masanobu Fukuoka, the One-Straw Revolution

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