Aquaponics: New Integrated Approaches for Sustainable Aquaculture and Agriculture

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In order to maintain symbiotic environment, a system that combines hydroponics with orthodox aquaculture is known as aquaponics. Cultivation of plants in water is called hydroponics and raising fish, prawns, bivalves, snails etc. in tank is called aquaculture. In ordinary aquaculture, the animal waste causes water pollution due to the excretions from the animal. As a result, toxicity of water is increased. To prevent this pollution, water from the aquaculture system is cleaned by hydroponic system where nitrification bacteria decomposes by-products into nitrates and nitrites, which are consumed as nutrients by plants. The water is then returned back to the aquaculture system. As current aquaculture and hydroponic systems form the root for all aquaponics structures, complexity and verities of foods grown in a system can vary as much as any system found in either different farming method [1].

Food sustainability is one of the major problems for future generations. Too much food production through agriculture process has significant impact on both environment and natural resources. To convert natural land to agricultural land, various chemicals are used which has serious influence on environment [2]. From the last twenty years, nitrogen content in the oceans has increased 20 times and brought severe eutrophication to water bodies for excessive use of chemical fertilizers [3]. To decrease waste, improve water and increase nutrient, a relationship or loop between crops and animals is established which is known as the aquaponics. Therefore, aquaponics is a way to maximize land use by combining two types of food production where water is scare and soil is poor.

The main two parts of aquaponics are aquaculture and hydroponics part for growing plants [4]. Though consisting mainly with these two parts, this system is typically grouped into numerous modules or subsystems that are responsible for effective waste removal of soil. Typical components include:

- Rearing tank: the containers for rising and nursing the fish.
- Settling basin: a unit for catching uneaten food and detached biofilms, and for settling out fine particulates.
- Biofilter: a place where the nitrification bacteria can grow and convert ammonia into nitrates, which are usable by the plants
- Hydroponics subsystem: the portion of the system where plants are grown by absorbing excess nutrients from the water;
- Sump: the lowest point in the system where the water flows to and from which it is pumped back to the rearing tanks.

In hydroponics systems, plants are grown in the nutrient-rich water. As a result, ammonia that is toxic for aquatic animals is filtered out from water. When the water is passed through the hydroponic system, it becomes clean, oxygenated and returns to the aquaculture vessels. This cycle is continuous. Common aquaponics applications of hydroponic systems include:

- Deep-water raft aquaponics: styrofoam rafts floating in a relatively deep aquaculture basin in troughs.
- Recirculating aquaponics: solid media such as gravel or clay beads, held in a container that is flooded with water from the aquaculture. This type of aquaponics is also known as closed-loop aquaponics.
- Reciprocating aquaponics: solid media in a container that is alternately flooded and drained utilizing different types of siphon drains. This type of aquaponics is also known as flood-and-drain aquaponics or ebb-and-flow aquaponics.

Other systems use towers that are trickle-fed from the top, nutrient film technique channels, horizontal PVC pipes with holes for the pots, plastic barrels cut in half with gravel or rafts in them. Each approach has its own benefits [5].

Most green leafy vegetables grow well in the hydroponic subsystem, although most profitable are varieties of Chinese cabbage, lettuce, basil, roses, tomatoes, okra, cantaloupe and bell peppers [4]. Other species of vegetables that grow well in an aquaponics system include beans, peas, kohlrabi, watercress, taro, radishes, strawberries, melons, onions, turnips, parsnips, sweet potato and herbs. Since plants at different growth stages require different amounts of minerals and nutrients, plant harvesting is staggered with seedlings growing at the same time as mature plants. This ensures stable nutrient content in the water because of continuous symbiotic cleansing of toxins from the water [1].

Freshwater fish are the most common aquatic animal raised using aquaponics, although freshwater crayfish and prawns are also sometimes used. In practice, tilapia are the most popular fish for home and commercial projects that are intended to raise edible fish, although barramundi, silver perch, eel-tailed catfish or tandanus catfish, jade perch and murray cod are also used [4]. For temperate climates when there isn't ability or desire to maintain water temperature, bluegill and catfish are suitable fish species for home systems. Koi and goldfish may also be used, if the fish in the system need not be edible.

Nitrification, the aerobic 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 [1]. 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 1.0 ppm) can kill fish. Although plants can absorb ammonia from the water to some degree, nitrates are assimilated more easily [4] thereby efficiently reducing the toxicity of the water for fish [1]. Ammonia can be converted into other nitrogenous compounds through healthy populations comprising of:

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

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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 where many bacteria can accumulate. Together with the concentrations of ammonia and nitrites in the water, the surface area determines the speed with which nitrification takes place. 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 biofiltering unit, which helps facilitate growth of these microorganisms. Typically, after a system has stabilized ammonia levels range from 0.25 to 2.0 ppm; nitrite levels range from 0.25 to 1 ppm, and nitrate levels range from 2 to 150 ppm. During system start-up, spikes may occur in the levels of ammonia (up to 6.0 ppm) and nitrite (up to 15 ppm), with nitrate levels peaking later in the start-up phase. 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 [1] if insufficient quantities are naturally present in the water to provide a buffer against acidification. 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 [1].

A good way to deal with solids build up in aquaponics is the use of worms, which liquefy the solid organic matter so that it can be utilized by the plants and/or other animals in the system.

The five main inputs to the system are water, oxygen, light, feed given to the aquatic animals, and electricity to pump, filter, and oxygenate the water. Spawn or fry may be added to replace grown fish that are taken out from the system to retain a stable system. In terms of outputs, an aquaponics system may continually yield plants such as vegetables grown in hydroponics, and edible aquatic species raised in an aquaculture. Typical build ratios are 0.5 to 1.0 square foot of grow space for every 1 US gal (3.8 L) of aquaculture water in the system. 1 US gal (3.8 L) of water can support between 0.5 lb (0.23 kg) and 1.0 lb (0.45 kg) of fish stock depending on aeration and filtration.

Ten primary 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 biofiltration
- Control pH

As in all aquaculture based systems, stock feed usually consists of fish meal derived from lower-value species. On-going depletion of wild fish stocks makes this practice unsustainable. Organic fish feeds may prove to be a viable alternative that relieves this concern. Other alternatives include growing duckweed with an aquaponics system that feeds the same fish grown on the system [6], excess worms grown from vermiculture composting, using prepared kitchen scraps [7], as well as growing black soldier fly larvae to feed to the fish using composting grub growers [8].

Aquaponics systems do not typically discharge or exchange water under normal operation, but instead recirculate and reuse water very effectively. The system relies on the relationship between the animals and the plants to maintain a stable aquatic environment that experience a minimum of fluctuation in ambient nutrient and oxygen levels. Water is added only to replace water loss from absorption and transpiration by plants, evaporation into the air from surface water, overflow from the system from rainfall, and removal of biomass such as settled solid wastes from the system. As a result, aquaponics uses approximately 2% of the water that a conventionally irrigated farm requires for the same vegetable production. This allows for aquaponics production of both crops and fish in areas where water or fertile land is scarce. Aquaponics systems can also be used to replicate controlled wetland conditions. Constructed wetlands can be useful for biofiltration and treatment of typical household sewage [9] The nutrient-filled overflow water can be accumulated in catchment tanks, and reused to accelerate growth of crops planted in soil, or it may be pumped back into the aquaponics system to top up the water level.

Aquaponic installations rely in varying degrees on man-made energy, technological solutions, and environmental control to achieve recirculation and water/ambient temperatures. However, if a system is designed with energy conservation in mind, using alternative energy and a reduced number of pumps by letting the water flow downwards as much as possible, it can be highly energy efficient. While careful design can minimize the risk, aquaponics systems can have multiple 'single points of failure' where problems such as an electrical failure or a pipe blockage can lead to a complete loss of fish stock.

Keywords— Aquaponics, Integration, Sustainable, Aquaculture, Agriculture,

REFERENCES

[1] Rakocy, James E., Bailey, Donald S., Shultz, R. Charlie and Thoman, Eric S. 2013. Update on Tilapia and Vegetable Production in the UVI Aquaponic System. University of the Virgin Islands Agricultural Experiment Station.

[2] Tillman, D., Cassman, K.G., Matson, P.A., Naylor, R. and Polasky, S. 2002. Agricultural sustainability and intensive production practices. Nature, 418: 671-677.

[3] Downing, J.A., Baker, J.L, Diaz, R.J., Prato, T., Rabalais, N.N. and Zimmerman, R.J. 1999. Gulf of Mexico Hypoxia: Land and Sea Interactions Task Force Report No. 134. Council for Agricultural Science and Technology, Ames, IA.

[4] Diver, S. 2006. Aquaponics – integration of hydroponics with aquaculture. ATTRA –National Sustainable Agriculture Information Service.

[5] Lennard, Wilson A. and Leonard, Brian V. 2006. A Comparison of Three Different Hydroponic Sub-systems (gravel bed, floating and nutrient film technique) in an Aquaponic Test System. Aquaculture International, 14 (6): 539–550.

[6] Rogosa, Eli. 2013. Organic Aquaponics. Retrieved April 24, 2013.

[7] Amadori, M. 2011. Fish, Lettuce and Food Waste Put New Spin on Aquaponics. Newswise. Retrieved April 24, 2013.

[8] Royte, E. 2009. Street Farmer. The New York Times Company. Retrieved 8 March 2011.

[9] Hygnstrom, J.R., Skipton, S.O.and Woldt, W. 2014. Residential Onsite Wastewater Treatment: Constructed Wetlands for Effluent Treatment. Retrieved June 15,2014.