North Central Regional
Aquaculture Center

Technical Bulletin Series

An Overview of Aquaponic Systems: Hydroponic Components

D. Allen Pattillo[1]

Introduction

Aquaponics is the union of hydroponics (growing plants without soil) and aquaculture (farming fish or other aquatic organisms) for a fast, efficient method of producing both plant and fish crops. Fish waste from the aquaculture portion of the system, is broken down by bacteria into dissolved nutrients (e.g., nitrogen and phosphorus compounds) that plants utilize to grow in a hydroponic unit (Figure 1). This nutrient removal not only improves water quality for the fish but also decreases overall water consumption by limiting the amount released as effluent. Aquaponics shares many of the advantages that hydroponics has over conventional crop production methods including:

1. reduced land area requirements,
2. reduced water consumption,
3. accelerated plant growth rates, and
4. year-round production in controlled environments.

This growing technique reduces crop production time considerably. For example, butterhead lettuce varieties can be produced in about 30 days, as opposed to the typical 60-day growing period needed under conventional methods. In the North Central Region (NCR) of the United States, aquaponic operations are typically operated year-round in a greenhouse or other controlled environment, which allow producers to take advantage of higher seasonal produce prices in the winter.

Aquaponics has additional advantages:

1. operational efficiency with shared equipment and
2. multiple crops produced simultaneously.

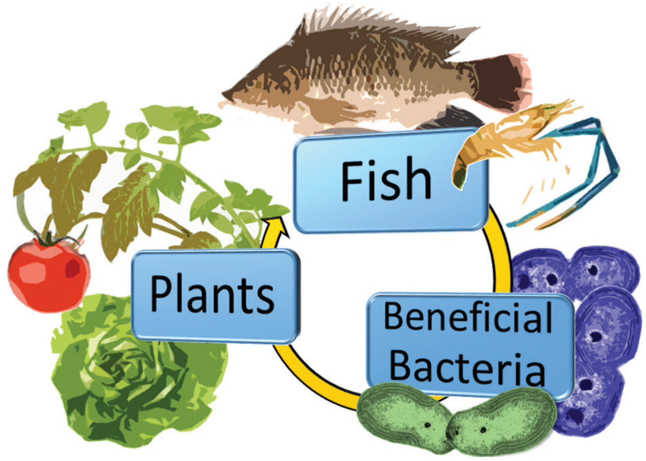

Figure 1. Components of an aquaponic system.

High-value herbs, vegetables, and leafy greens, as well as fish, crayfish, worms, and a number of other products can be produced to meet a highly diversified market. Because aquaponic systems are often closed-loop systems (i.e., waste generated during production is recycled within the system), nutrient effluence is virtually non-existent, allowing agriculture to take a large step toward environmental sustainability. Moreover, fish, plant, and waste solids can be captured and converted into fertilizer products for additional sale. These benefits make aquaponic systems a viable option for gardeners and producers who have limited space, giving more people access to locally produced, healthy foods.

This publication is part of an aquaponics series with information relevant to the NCR and will cover the five most common categories of hydroponic crop production techniques, controlled environments, and mineralization.

[1] Iowa State University Extension and Outreach

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Hydroponic Growing Methods Used In Aquaponics

There are many ways to grow plants hydroponically and many of these techniques have been adapted for use in aquaponic systems. The five most common categories of hydroponic growing methods used in aquaponic systems include flood and drain, deep water culture, nutrient film technique, drip irrigation, and vertical growing systems. Each of these methods are effective at growing plants, but certain systems may be favorable under different scenarios. Figure 2 describes the aquaponic system developed at Iowa State University.

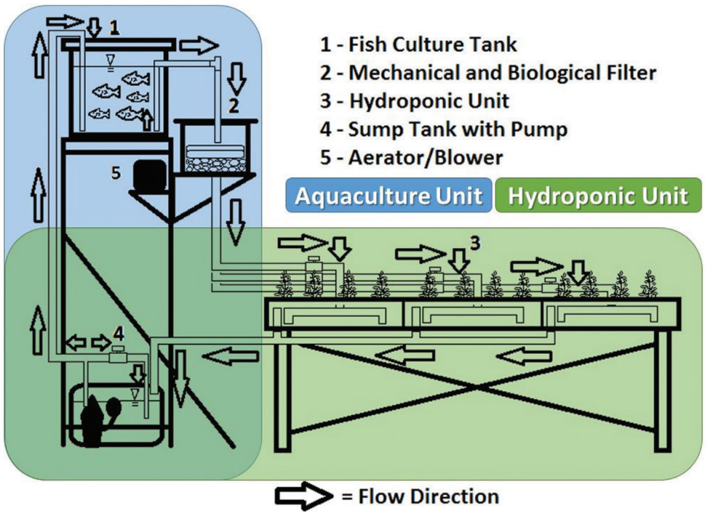

Figure 2. Schematic representation of the aquaponic system used at Iowa State University.

Flood and Drain – Flood and drain (a.k.a. ebb and flow; Figure 3) irrigates the plants by filling the hydroponic unit with nutrient-rich water followed by a period of draining, which draws air into the root zone. The periodic emersion in water, followed by air exposure, introduces oxygen to the roots, producing an environment conducive to healthy roots. This method requires the use of a coarse substrate like pea gravel, expanded clay, perlite, and others to support the plant roots, while providing excellent drainage. Flood and drain systems utilize the substrate for both root stability and the high surface area of the substrate for biological filtration.

Cycling between wet and dry can be controlled by several methods including a pump on a timer, an indexing irrigation valve, or the automatic siphon method. Generally hydroponic units are drained every 20-30 minutes to incorporate oxygen in the root zone. Depending on the moisture holding capacity of the substrate and the ability of the plant to tolerate their roots sitting in water, duration of this cycle will vary. The Iowa State system has successfully grown leafy greens using a 15-minute flooding and 45-minute draining cycle during the 12 daylight hours, which is achieved with a 150 gallon/hour (550 liter/hour) pump on an electric timer.

Figure 3. A large flood and drain grow bed.

Automatic siphons are used to quickly drain the hydroponic unit. This is generally achieved by using a loop siphon with either hard or soft plumbing, or a bell siphon (Figure 4). A siphon (Figure 5) occurs when water in a vessel at a raised elevation has a tube or pipe submerged in it, and that tube, when completely filled with water and no air, creates a vacuum that allows the water to be transported from one vessel to another by gravity flow. A bell siphon uses an inverted chamber encompassing a stand pipe that

Figure 4. A bell siphon chamber (left) and stand pipe inside a permeable pipe (right).

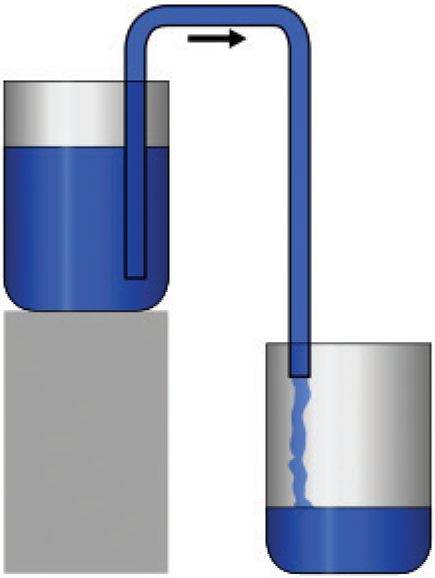

Figure 5. Basic diagram of a siphon.

creates an air lock causing a siphon to form as the air exits from the chamber, and the water continues to flow until air is reintroduced into the chamber through the arches at the bottom of the chamber. Flow rate and pipe diameter ratios are critical in creating this phenomenon, as greater flow rates are needed to create suction required to evacuate air from the chamber. If the gap between the standpipe and the chamber is too great a siphon will not form, but if it is too narrow the siphon will break before the hydroponic unit is drained.

The outflow from the hydroponic unit should be guarded by a permeable pipe (Figure 4) that will hold back the substrate while allowing water to flow freely through it. Care should be taken to keep the plumbing flow unobstructed, as small diameter gravel will tend to fall into the outflow pipes. In the Iowa State system, an 8-inch (20-cm) section of 4-inch (10-cm) diameter corrugated plastic tile drain line with 1-inch (25-mm) slots is used to keep the gravel substrate away from the drain.

Deepwater Culture – This method, also known as floating raft culture, is the most commercially adopted technique because of its simplicity and reliability. Deepwater culture (Figure 6) uses a floating or suspended platform with holes to support the plants and allows roots to be submerged in the water. Polystyrene insulation is typically used as the raft and plastic net pots support the plants, although some new food-grade materials have been developed. The rafts provide many benefits including ease of use, mobility, simple cleaning, and lower risk of plant mortality during power outages. Plants in a deep water culture unit may live up to 2 weeks without water flow or aeration as compared to hours or days in other systems.

Figure 6. Deepwater culture using a floating raft.

Oxygen content in the water can be a major struggle in deepwater culture because of the high biological oxygen demand (BOD), defined as the need for oxygen for respiration by the plants, animals, and bacteria in this biologically-rich system. Aeration should be supplied via diffusor airstones placed every 4 feet (1.2 meters) under the rafts to prevent stagnation and oxygen deprivation in the root zone.

When using this method, water depths may range from 4 inches (10 cm) to 3 feet (1 m) or more, but a typical depth is 12-24 inches (30-60 cm). Although there are commercially available containers created specifically for deepwater culture of plants, many hobbyists choose to construct their own using a variety of materials and dimensions. Since many do-it-yourselfers will go to the local home improvement store to purchase materials, system designs generally conform to the dimensions of the readily available materials (e.g., 4-foot (1.2-m) increments) to reduce labor. Typical building materials include pressure treated lumber, galvanized steel tubing, or masonry blocks, all of which are covered with a plastic, polyvinyl chloride (PVC), heavy duty tarp, or rubber pond liner to hold water. The materials are generally chosen for availability, price, durability, and structural stability depending on the volume, shape, and life expectancy of the container. Not all construction materials are considered food-grade, and care should be used in their selection, particularly if the produce is to be sold.

Figure 7. Nutrient film technique (NFT).

Nutrient Film Technique (NFT) – The nutrient film technique (Figure 7) utilizes the contact of the root zone with a thin film of water (approximately 1/4-1/2 inch (5-10 mm) deep) that flows along a smooth surface where the roots of the plants can contact both air and water simultaneously. This is commonly done inside a channel or gutter style system made from white extruded PVC material. These channels vary in width (4-9 in or 10-23 mm) and depth (1.5-4 in or 4-10 cm), depending on the size of the plants being grown. Plants like basil and lettuce can be grown in smaller channels, whereas tomatoes, cucumbers, and peppers are grown in larger channels to accommodate the larger root mass associated with the plants. The slope of these systems range between 1 and 4 percent (slope = rise/run), and flow rates between 0.25-0.5 gallons (1-2 liters) per minute. Water is delivered into the channels via opaque tubing that ranges in diameter based on the clarity of the water source and biofouling from bacteria and algae.

Figure 8. Nutrient film technique (NFT) installed over deep water culture.

An advantage to this system is its light-weight design, which allows vertical installation of channels over one another or above a deepwater culture system. They should be spaced so light is able to penetrate all crops (Figure 8). The channels are mobile, making it easy to change row spacing or add or remove channels from the system, creating flexibility for harvest methods.

Small diameter irrigation line (spaghetti tubing) is prone to clogging in aquaponic systems and should be avoided. Instead, replace the tubing with 5/8-inch (16-mm) diameter or greater hose (Figure 9). Inadequate flow rates, channelization of water flow, and clogging with massive roots leading to nutrient deficiencies, wilting, variable crop production, and plant mortality.

Figure 9. Nutrient film technique modified for aquaponic systems with a garden hose.

Drip Irrigation – Drip irrigation systems (Figure 10) use a substrate for growing plants that provides the root zone with a constant supply of water and air. Common methods include (Dutch or Bato) bucket culture and slab culture, and are typically used for large fruiting crops like tomatoes, cucumbers, and peppers. Bucket culture combines the concepts of flood and drain and NFT, creating a modular, mobile growing method for large vining crops. Bucket culture substrates generally include perlite, pea gravel, expanded clay, or rockwool.

Figure 10. Drip irrigation in bucket culture.

Slab culture (Figure 11) is similar to NFT culture, but the water is injected directly into the plant root zone. A commercially available, multi-stage growing method commonly used includes small (1-1.5 in or 2.5-4 cm diameter) starter plugs followed by an intermediate (4x4x4 inch or 10x10x10 cm) block and slab (6x6x24 in or 15x15x60 cm). The substrate is generally covered with plastic to prevent algae growth. Slabs, blocks, and plugs may be made of rockwool, coconut coir, or other materials. Coconut coir has the added sustainable benefit of being compostable.

Figure 11. Slab culture using drip irrigation.

Vertical Growing Systems – Vertical growing systems maximize the production output of a growing area by taking advantage of the 3-dimensional space, which may be important for farmers in urban areas where growing space can be expensive. Vertical growing may involve multiple layers of deepwater culture, NFT (Figure 12), flood and drain systems, or growing towers that involve aeroponic growing methods, in which the plant roots are suspended in the air and sprayed with nutrient rich water (Figure 13).

Figure 12. Vertical plant production using deep water culture and NFT.

Figure 13. Vertical growing tower.

A growing tower is designed so that water is pumped from the sump up to the top of the tower and onto a diffuser plate, creating "rain" inside the tower as it drips over the plant roots that are suspended in the air. Towers may be empty (hollow) or filled with a substrate that provides plant structure and aids in water dispersal. Biofouling in an aquaponic system is typical, and vertical systems are particularly susceptible to clogging and reduced flow rates that may starve the plants for water. A routine pressure washing of system components to remove any biofouling is highly recommended for success.

Mineralization

Fish feed typically has 10 of the 13 required nutrients (Table 1) plants need to thrive under aquaponic growing conditions. The three potential limiting nutrients are calcium (Ca), potassium (K), and iron (Fe). The remaining nutrients are available for plant uptake after the feed is consumed by fish and later excreted as waste materials. These wastes are processed by bacteria present in a mature system.

Table 1. Required nutrients for plant growth in aquaponic systems.

Nutrient Type	Nutrient (symbol)
Macronutrient	Nitrogen (N)
	Phosphorus (P)
	Potassium (K) *
	Sulfur (S)
	Calcium (Ca) *
	Magnesium (Mg)
Micronutrient	Iron (Fe) *
	Chlorine (Cl)
	Molybdenum (Mo)
	Boron (B)
	Copper (Cu)
	Manganese (Mn)
	Zinc (Zn)

* Denotes nutrients typically lacking from fish feeds.

A mineralization tank (Figure 14) is highly agitated with aeration, creating an opportunity for bacteria to consume waste products and liberate bioavailable nutrients. The process of bacterial digestion and breakdown of feed generally occurs under aerobic (oxygenated) conditions. Periodically aeration is stopped for a period of 20-60 minutes, allowing the solids to settle to the bottom. This process clarifies the water, and the top water layer is then added to the hydroponic unit.

Figure 14. Aerated mineralization tank.

Anaerobic digestion is a process that uses bacterial decomposition in an oxygen-free environment to break down the fish waste, producing gasses like methane (CH_4)

Figure 15. Polycarbonate greenhouse growing environment.

that can be captured and burned as an electricity and heat source and generate CO_2 for plants. This process also generates liquid fertilizer that can be added back to the hydroponic unit and solid fertilizer that can be used in the germination of seedling plants.

Recent research suggests that a combination of aerobic and anaerobic digestion techniques may benefit plant nutrient availability. Variations on these techniques may provide the optimal combined benefits of aerobic and anaerobic waste digestion.

Controlled Growing Environment

The growing environment is critical for plant production. At present, the majority of available reliable aquaponics research has been conducted in tropical climates where growing conditions are ideal year-round. In the NCR, however, hot summers and cold winters tend to limit the growing season and production options available to producers. Research and extension efforts are currently underway to educate producers on optimized techniques in the NCR.

The ability to regulate temperature, light intensity, humidity, and to shelter the production system from the elements helps optimize growth rates for crops as well as ensure biosecurity and food safety. A controlled environment may be a warehouse, classroom, basement, garage, greenhouse, or other structure that shields the growing system from the external environment. Greenhouses (Figure 15) are commonly used for year-round crop production because of their heat retention and the transmission of sunlight through the structure. Warehouses have become popular for vertical growing systems because of their availability in or near cities and their ability to insulate the crops from prevailing weather conditions. A warehouse environment will require the use of artificial light, a major energy input. Farmers can work with their local power company to obtain reduced electrical pricing rates by using 'off-peak' power when the typical energy demand by other consumers is low (i.e., nights, weekends, and holidays). Operational efficiency can be gained by using the heat generated by certain types of grow lights and pumps used in the system to somewhat reduce heating requirements. Additionally, some producers choose to generate their own electricity with an internal combustion generator, creating electricity, heat, and carbon dioxide – all beneficial in plant production.

Renewable energy sources are growing in popularity and becoming more affordable for producers. Some government programs provide incentives for using renewable energy sources as well. Solar and wind energy are ways to reduce a farm's carbon footprint and become more energetically independent from the power grid. Geothermal heating and cooling is one option for curtailing the summer and winter temperature variations experienced by greenhouse growers in the NCR. Installing these types of systems generally requires a large investment, so farmers considering these options should look into the capital cost of the infrastructure and compare it to the equipment's useful lifespan as well the payback period required to recoup the upfront cost.

Conclusions

Aquaponic systems present a unique opportunity for year-round production of plants and fish. Out-of-season production of leafy greens, herbs, and vegetables can be a major source of income for aquaponic producers, as they can take advantage of much higher seasonal prices. The high quality and freshness of aquaponic produce is highly desired by chefs in metropolitan areas. If aquaponic producers can fill the seasonal gaps with fresh produce, buyers are more likely to keep them as a vendor, allowing producers to capture a larger market share. Additionally, the local foods movement and consumer willingness to pay more for a superior product is a major advantage to aquaponic producers.

Aquaponics can be done on a wide range of scales; from a bench-top aquarium for the hobbyist to a multi-acre commercial facility capable of producing substantial amounts of fish and plants per year. As in other agriculture operations, profitability in the aquaponics business model is related to scale and efficiency of production.

Research conducted at Iowa State suggests that it may be possible to generate a profit when producing tilapia and basil in a greenhouse facility in Iowa. This system model demonstrates that the value of the fish (tilapia) produced has very little effect on profitability, but rather the price and amount of plants (basil) produced often determines economic viability.

Aquaponics may be an attractive opportunity for individuals wanting to change their lifestyle to a slower pace with a modest income. In a well-designed and efficiently run aquaponics facility, the ability to profit is greater as the plant growing area increases because of increased product output, efficient use of resources, stability of the system, and regularity of production. However, a larger facility does not necessarily mean more profit. One should consider supply and demand principles and wholesale versus retail pricing to determine the actual returns to the farmer. It is critical, therefore, for potential aquaponic farmers to do their due diligence in business planning and market research as well as hands-on education prior to investing in an aquaponics business to ensure success.

Suggested Readings

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Recommended Videos

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Resource Pages

Agricultural Marketing Resource Center http://www.agmrc.org/

Aquaponics Association http://aquaponicsassociation.org/

Aquaponics Journal http://aquaponicsjournal.com

ATTRA National Center for Appropriate Technology https://attra.ncat.org/

Iowa State University Extension Online Store https://store.extension.iastate.edu

Iowa State University Food Safety Extension http://www.extension.iastate.edu/foodsafety/

Iowa State University Fisheries Extension http://www.nrem.iastate.edu/fisheries/

Leopold Center for Sustainable Agriculture https://www.leopold.iastate.edu/

North Central Regional Aquaculture Center www.ncrac.org

Southern Regional Aquaculture Center – Aquaponics Publication Series https://srac-aquaponics.tamu.edu/

Sustainable Agriculture Research and Education Program http://www.sare.org/

USDA – National Agricultural Library https://www.nal.usda.gov/afsic/aquaponics

University of Minnesota Aquaponics http://www.aquaponics.umn.edu/aquaponics-resources/

Texas A&M Aquaponics http://fisheries.tamu.edu/aquaponics/

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USDA United States Department of Agriculture

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