Texas A&M AgriLife Extension

EHT-136
2/20

What is AQUAPONICS?

Joseph Masabni[1] and Todd Sink[2]

The term "aquaponics" is the combination of two words: aquaculture and hydroponics. Aquaculture is the science of raising fish, while hydroponics is the science of growing plants in a soilless media or nutrient solution. Therefore, aquaponics is a combination of these two food production systems.

Most of the world's aquaculture production takes place in earthen ponds or raceways; these systems are either static or flow-through. Fish in these systems produce nitrogenous and mineral wastes that require extensive filtration. In hydroponics, inorganic fertilizers are used as the source of nutrients for plants, which requires flushing the system regularly to replenish the fertilizer solution or to remove any excess salt accumulation. In an aquaponic system, ammonia (NH_3) excreted by fish as a waste product from protein metabolism is converted to nitrate (NO_3-) by nitrifying bacteria. Plants act as a water filtration system by absorbing nitrogenous and mineral products, which improves water quality for the fish. The nitrifying bacteria convert fish waste products into usable nutrients for the plants, and the plants filter the nutrients from the water to benefit the fish (Figs. 1 and 2). Therefore, fish, nitrifying bacteria, and plants benefit from each other.

Aquaponics is a unique ecosystem within a food production system where fish, bacteria, and plants are mutually benefiting from each other. In other words, aquaponics is the combination of both intensive aquaculture and hydroponic production systems in a recirculating water system.

The immediate benefits of aquaponics are reduced costs of fish waste filtration by conventional methods, and, more importantly, inorganic fertilizers and associated costs of fertilization management are no longer required. An aquaponic system requires water, fish feed, and electricity for the water and air pumps. There

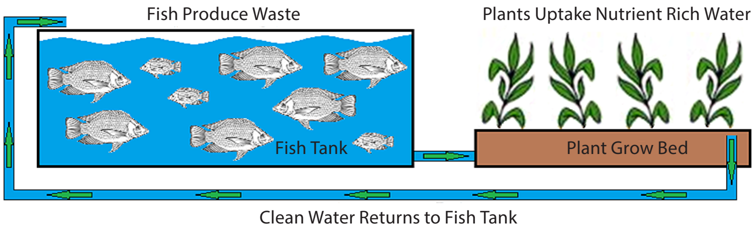

Figure 1. Schematic representation of an aquaponic system.

Figure 2. Backyard aquaponics model with room for 12 plants.

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[1] Extension Small-Acreage Vegetable Specialist, Department of Horticultural Sciences, and [2] Extension Fisheries Specialist–Department of Wildlife and Fisheries Sciences, The Texas A&M University System

Figure 3. Live lettuce plant ready for storage or sale.

are many benefits to implementing an aquaponic system. For example, aquaponic systems are 100 percent natural, since no synthetic fertilizers are used. Other system advantages include low water consumption, fast and efficient food production, and less filtration equipment and costs are required as plants act as filters. Additionally, harvested plants remain alive since the roots are not cut at harvest. Live plants store longer in a refrigerated cooler, staying crisp and still tasting fresh 2 weeks later (Fig. 3). Live plants stored in this manner have been successfully replanted in a garden, demonstrating the plant freshness when harvested in this manner.

It can be an easy step for an existing hydroponics producer to convert a hydroponic system into an aquaponic system. Conversion of a hydroponic system means the addition of one or more tanks for filtration, a fish tank, some extra PVC plumbing, and then the old system becomes a new aquaponic system.

The crucial component of aquaponics is the nitrifying bacteria. The conversion, or nitrification, of ammonia excreted by fish does not occur automatically. While fish produce ammonia—the fuel that runs the system—bacteria are considered the engine running the aquaponic system. Daily maintenance activities revolve around maintaining an optimal environment for the bacteria, while daily water quality measurements indirectly measure the health of the bacteria.

Two types of bacteria act in stages to convert ammonia, or fish waste, into usable nitrates and minerals for plant nutrition. The two types of bacteria are *Nitrosomonas* and *Nitrobacter*. *Nitrosomonas* convert ammonia to nitrite. *Nitrobacter* then converts the nitrite to nitrate. Ammonia is a natural product of fish protein metabolism. Freshwater fish excrete ammonia from their gills and in their feces. Excessive concentrations of un-ionized ammonia in water are toxic to fish. The amount of un-ionized ammonia in the water depends upon the total ammonia nitrogen (TAN) present and the water pH and temperature. Un-ionized ammonia (NH_3) is toxic to most fish species at concentrations of 1 part per million (ppm) or less. The conversion of ammonia to nitrite by *Nitrosomonas* slightly reduces the risk of fish toxicity. However, nitrite is not readily usable for plant growth. Therefore, *Nitrobacter* is also crucial as it converts nitrite to nitrate, which is relatively non-toxic to fish, easily absorbed by plant roots, and necessary for plant growth.

The biotic, or living, components of an aquaponic system are fish, plants, and two genera of bacteria, all working in unison (Fig. 4).

The abiotic, or non-living, components of an aquaponic system consists of a fish tank(s), clarifier or solid waste filtration tank, biofilter, plant growing beds, a water pump, and an air pump (Fig. 5). Many designs combine one or more of those basic components in production. Some systems using "low-density" methods may consist of only a fish tank and trough(s). Systems using "high-density"

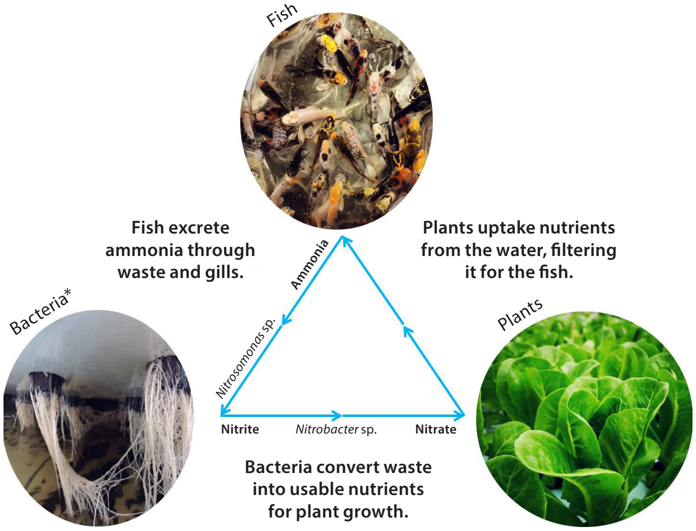


Figure 4. The aquaponic nitrogen cycle.

*bacteria colonizing a root system

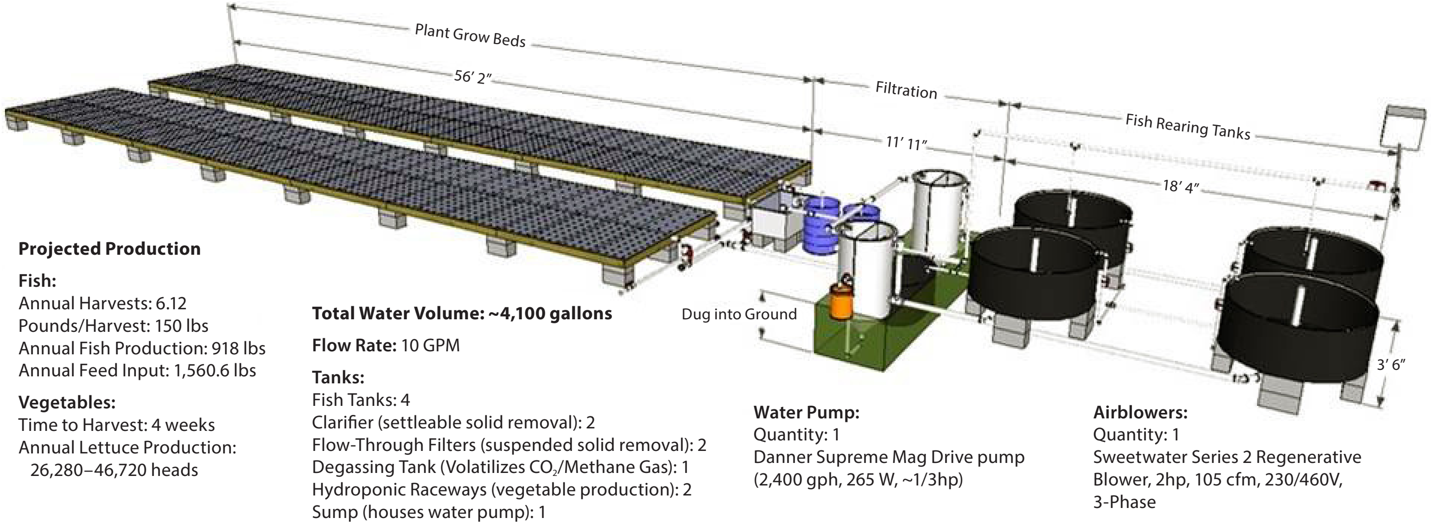
methods may consist of all the parts mentioned above, plus a media bed. Additional components sometimes used on a commercial scale include a "base supplementation" tank to adjust or amend water so that fish and plants are not immediately exposed to rapid pH or other water-quality changes.

Fish tanks, of course, are where the fish are housed. A properly constructed aquaponic system should include at least two fish tanks. Some large commercial operations have four or more fish tanks. Two fish tanks are strongly encouraged, even for backyard or hobby systems. Two tanks are beneficial for many reasons. Separating fish of various sizes reduces the risk of cannibalism. With a single fish tank, you cannot harvest the entire tank at once without the risk of running out of nutrients for the plants. With two fish tanks, all the fish in one tank may be harvested quickly, efficiently, and economically, while continuing to supply nutrients for the plants from the other fish tank. Partial fish harvest and replacement with fingerlings increases the risk of loss due to cannibalism for many species, so it may not be feasible to have a single tank for some species. A minimum of two fish tanks is the ideal solution.

Imagine you have two fish tanks, with fingerlings in one and medium-sized fish, about ½ pound, in the other. When the larger fish mature and are ready for sale or consumption, usually at about 1 pound, then the fingerlings are now at ½ pound. Adding fingerlings in the tank that was just harvested will bring you back to where you started: one tank with fingerlings, the other with mid-size fish. Depending on your greenhouse size or the size of the troughs, fish tanks can range from a 100-gallon tank to a 1500-gallon tank.

Most commercial aquaponic startups do not consider fish as part of the business plan. A common myth exists that aquaponics is cheaper than hydroponics; this is not the case. One ton of 32 percent fish feed costs about $485 and supplies 305 pounds of nitrate. A similar amount of nitrate supplied from urea in a hydroponic system costs only $107. If you plan to run a commercial aquaponic operation, fish must be sold to cover operational costs. Finally, some fish species are poor choices in aquaponics. Examples of poor choices are catfish, bluegill, goldfish, or any other non-food fish with limited sales outlets. The best choices are tilapia, hybrid striped bass, and rainbow trout in northern climates. As a rotational winter crop, the most suitable options would be tilapia in summer, and koi, but only where there is a significant retail outlet for large koi.

The clarifier comes in many shapes and under different names, such as the solid waste filter, radial filter, swirl filter, or solids settling tank. The primary function of the clarifier is to separate the solid waste



Projected Production

Fish:
Annual Harvests: 6.12
Pounds/Harvest: 150 lbs
Annual Fish Production: 918 lbs
Annual Feed Input: 1,560.6 lbs

Vegetables:
Time to Harvest: 4 weeks
Annual Lettuce Production:
26,280–46,720 heads

Total Water Volume: ~4,100 gallons

Flow Rate: 10 GPM

Tanks:
Fish Tanks: 4
Clarifier (settleable solid removal): 2
Flow-Through Filters (suspended solid removal): 2
Degassing Tank (Volatilizes CO_2/Methane Gas): 1
Hydroponic Raceways (vegetable production): 2
Sump (houses water pump): 1

Water Pump:
Quantity: 1
Danner Supreme Mag Drive pump
(2,400 gph, 265 W, ~1/3hp)

Airblowers:
Quantity: 1
Sweetwater Series 2 Regenerative
Blower, 2hp, 105 cfm, 230/460V,
3-Phase

Figure 5. Schematic representation of an aquaponic system.

from the nutrient-rich water (Fig. 6). Most clarifiers rely on reduced water and gravity to settle solid waste at the bottom of tanks to be drained out regularly.

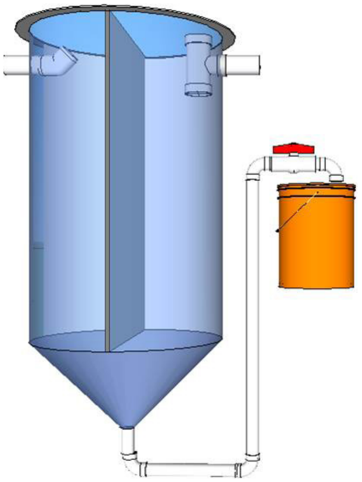


Figure 6. Schematic diagram of a clarifier tank for solid waste separation.

Some systems employ two clarifier tanks in a series (Fig. 7) to remove most, if not all, the solid waste. This solid waste is not truly a waste. It is still rich in nutrients and should be used efficiently instead of being discarded. The solid waste can be placed in a separate tank and aerated for a few days, filtered, and the resulting product, or "compost tea," can be put back in the aquaponic system. The filtered compost tea can also be used as fertilizer in the garden. Alternatively, the solid waste can be added to a vermicompost bin as a source of food for the worms (Fig. 8).

The biofilter is where large numbers of nitrifying bacteria are housed on inert media with a high surface area. The biofilter is the primary site for the conversion of ammonia to nitrites and nitrates. There are many approaches to building a biofilter, just as long as you use an inert media with a very large surface area in contact with the water. There are also numerous biofilters available commercially. Ammonia conversion becomes more efficient with increases in the surface area provided by the media. Commonly used materials are nylon or PVC bird netting, lava rock, polyethylene filter pads, biomatrix pads, polyester filter fiber, floating or sinking plastic beads, and fine-pore porcelain. Various other plastic media, including bio-balls, bio-barrels, bio-stars, and bio-tubes, are also commonly used. Once the system is operational or has "matured," nitrifying bacteria can be found on every inert surface exposed to sufficient oxygen and little organic debris, including the growing troughs, plant roots, in the pipes, and on all other tanks. Still, the majority of biofiltration, or ammonia conversion, will take place in the biofilter. Commercial units that combine the clarifier and biofilter in a single unit are available, although it is preferable to keep solid wastes separate from areas containing nitrifying bacteria. Some operations use a media bed as biosolid digestion (Fig. 9). Media beds can also be planted so as not to waste valuable space.

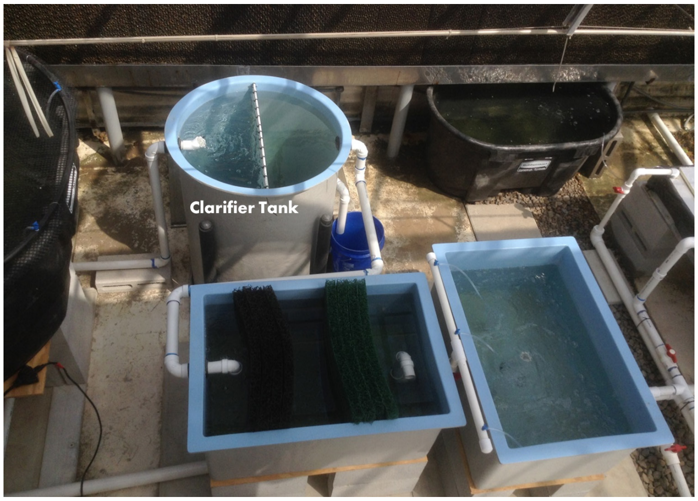


Figure 7. Two clarifier tanks connected in a series. The first one (top tank) relies on gravity to separate solids, the second (bottom left tank) relies on netting.


Figure 8. Earthworms in a media bed made of crushed granite, acting as another step for solid waste filtration.

The base tank serves the purpose of an additional point to add water amendment products when adjusting the pH of the aquaponic system. The alkalinity and pH of water in an aquaponic system tend to decrease over time due to the consumption

Figure 9. Media bed for solid waste filtration.

and utilization of carbonates during bacterial processes and plant growth. Decreases in pH can be rapid, especially if a rain event adds a large volume of water to an open-air system. The water pH should be checked regularly and adjusted by adding a base, bringing it as close to a neutral pH of 7 as possible. Chemical bases such as calcium carbonate ($CaCO_3$), calcium hydroxide ($Ca(OH)_2$), calcium oxide (CaO), or potassium bicarbonate ($KHCO_3$) are available products for raising pH. Crushed oyster shells, a form of calcium carbonate, are also popular among small-scale operations and homeowners. Oyster shells in a mesh bag submerged in the tank will act as a buffer by slowly and continuously adjusting the water pH. However, oyster shells may not be sufficient alone.

The growing troughs or tanks are where plant production occurs. There are currently three types of troughs used in aquaponics. Media beds are filled with materials such as expanded clay pellets or pH neutral rock and are usually operated using the flood and drain method (Fig. 10). The media bed is set to fill with water during 20-minute intervals, then a float-valve, inverted siphon, or other drain mechanism is activated, and the water is drained over a 10-minute period. This continuous flood and drain cycle guarantees that the plant roots never become dry or wet for too long. Expanded clay is expensive, and many growers use other materials like pea gravel or crushed granite. In this case, it is important to use pH neutral rock alternatives. To test if the rock is pH neutral, add vinegar to a small amount of rock. If it starts bubbling, the rock is not suitable for an aquaponic system, no matter how well it is washed before use. The advantage of a media bed is that larger fruiting vegetable plants can be grown in this media. The expanded clay provides physical support for the roots of those large plants. The disadvantage of media beds is that large areas

Figure 10. Flood and drain trough filled with expanded clay (left) or crushed granite (right).

can become clogged, creating areas lacking oxygen, which requires frequent cleaning of the media.

The second type of growing trough uses the nutrient film technique (NFT), commonly used in hydroponic operations. PVC pipes, gutters, or similar materials can be used for system construction (Fig. 11). In this system, a thin layer of water is continuously running through the pipes, and the plants' roots are constantly exposed to nutrient-rich water. No additional aeration is needed. This system is suitable for small-sized plants such as leafy greens. Larger plants will have larger roots, which will clog the pipes or gutters. One disadvantage of the NFT is that water temperature can warm up very quickly due to smaller volumes and thin sheets of water. However, with the addition of water chillers, lettuce production using the NFT can be done year-round.

Figure 11. Various lettuce cultivars are grown in an NFT system.

The third and most popular type of growing trough is the deep water raft culture system (DWRC or DWC) (Fig. 12). In this system, a rigid foam board floats on the surface of a relatively deep water trough that is continually filled with water, and transplants are placed in holes in the foam board so that roots are submerged in water. Supplemental aeration from air stones or an air pump is absolutely vital for plants in a DWRC system. Troughs can be as shallow as 6 inches and as deep as 24 inches, although 18 inches is the typical standard. Troughs do not have to be on the ground. The troughs can be built on a bench or table, but caution should be observed as the water weight can be substantial. The DWRC system is very popular among commercial operations specializing in leafy greens such as lettuce and kale.

Figure 12. Deep water raft culture with lettuce at various stages of growth.

In a typical aquaponic system, the fish tanks are the highest point in terms of water level. Water cascades from the fish tank (black), to the clarifier(s), to the biofilter, to the supplemental aeration tank (blue barrels), and then to the growing trough (not shown) (Fig. 13).

The base tank is usually located at or near the return pump at the end of the production troughs, which is the lowest water level in the system. Hence, a water pump is necessary to push the water back up to the fish tank. This is normally the only water pump that is needed in an aquaponic system. Airlift systems use the blower supplying air to the fish and plants to return water to the fish tanks.

Figure 13. Cascading flow of water from fish tanks to the trough (not shown).

When purchasing a water pump, keep in mind that the flow rating of a pump is for a pump pushing water horizontally. If the pump must push water up or vertically, the flow rating drops significantly. For example, a water pump rated at 500 gallons per hour (gph) can push water an elevation of 3 feet (head height) at 300 gph only. Therefore, most pumps carry a graph of flow rate in gallons per hour versus head height. When choosing a water pump, select one that can circulate the entire volume of water in the whole system a minimum of three times per day. For example, in a system with 1,000 gallons of water total, and a 500-gph pump pushing 300 gph of water up 3 feet of head, you achieve a complete turnover every 3.3 hours, or 7.3 times per day.

An air pump or blower is the only other component using electricity. The air pump should be connected via pressure tubing to airstones placed in the bottom of the fish tank(s) and growing trough(s).

One final component, not commonly considered when building an aquaponic system but is of utmost importance, is a backup generator. In the case of a power outage, plant roots can survive in low-oxygen levels for about 12 to 24 hours without significant damage. On the other hand, fish can suffocate in as little as 30 minutes to 4 hours depending on stocking density and time of the year after a power outage.

In summary, aquaponics offers many advantages to the homeowner or commercial producer. Aquaponics serves a dual purpose of producing both fish and plants as food. Plants in an aquaponic system tend to grow faster than in an open field and use about 10 percent of the water needed. Most importantly, aquaponics produces fresh, healthy vegetables that were not treated with any chemical pesticide or inorganic fertilizer. Aquaponics is not restricted to commercial operations. Many homeowners install home-scaled systems for their enjoyment and consumption (Fig. 14).

Figure 14. Backyard system using barrels as growing beds (left) and home system with an aquarium (right).

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