AgriLife Extension Solutions

What is Aquaponics?

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The word *aquaponics* is the combination of two words, aquaculture and hydroponics. Aquaculture is the science of raising fish and hydroponics is the science of growing plants in a soilless media. Therefore, aquaponics is the combination of those two food production systems into one.

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

Figure 1. Schematic representation of an aquaponics system

Thus, aquaponics is a unique ecosystem within a food production system, where fish, bacteria, and plants are mutually benefiting 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 aquaponics system requires the following inputs: water, fish feed, electricity for the water and air pumps, and light. Advantages of such a system are it is 100% organic since no synthetic chemicals are used, fast and efficient food production, low water consumption, and less filtration equipment and costs are required as plants act as filters. Another

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

advantage is the harvested plants remain alive since the roots are not cut at harvest. Live plants store longer in the refrigerator, remaining crisp and still taste well 2 weeks later (Figure 3). Plants stored in a refrigerator for 2 weeks have been removed, planted in a garden, and started growing again, thus demonstrating the plant freshness retained by harvesting in this manner.

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

The most crucial component of an aquaponics is the nitrifying bacteria. Conversion, or nitrification, of ammonia excreted by fish does not occur automatically. Two genera, or types, of bacteria act in stages to convert fish waste into usable nutrients for the plants. While fish produce the fuel to run the system, bacteria are considered as the engine running the aquaponics 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.

The two types of bacteria are, *Nitrosomonas* and *Nitrobacter*. *Nitrosomonas* convert ammonia which is highly toxic to fish to nitrite which is slightly less toxic to fish. *Nitrobacter* then convert nitrite to nitrate, which is relatively non-toxic to fish and is the most available form of nitrogen available for plant uptake. Ammonia is a natural product of fish protein metabolism. Freshwater fish excrete ammonia from their gills and in 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 or less. Conversion of ammonia to nitrite by *Nitrosomonas* slightly reduces the risk of fish toxicity. However, nitrite is not a readily usable form for plant growth. Therefore, *Nitrobacter* is crucial as it converts nitrite to nitrate, which is relatively non-toxic to fish and is the nitrogen form easily absorbed by plant roots and is necessary for plant growth.


Figure 3. Live lettuce plant ready for storage or sale

The biotic, or living, components of an aquaponic system are thus fish, plants, and two genera of bacteria, all working in unison (Figure 4). The abiotic, or non-living, components of an aquaponic system consist of a fish tank(s), clarifier or solid waste filtration tank, biofilter, plant growing beds, tanks, or troughs, a water pump, and/or an air pump (Figure 5). There are many designs currently employed that 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' methods may consist of all the above-mentioned parts plus a media bed. Additional components sometimes used on a commercial scale include a 'base addition' tank to add water quality amendments 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 aquaponics system should include at least two fish tanks. Some large commercial operations have four or more fish tanks. Two fish tanks are strongly encouraged for even backyard type 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 fish in one tank may be harvested quickly, efficiently, and economically, while continuing to supplying nutrients for the plants from the other fish tank. Partial fish harvest and replacement with fingerlings increases the risks for losses 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.

Figure 4. The aquaponic nitrogen cycle

Imagine you have two fish tanks and with fingerlings in one and medium-sized fish (about ½ lb.) in the other. When the larger fish mature and are ready for sale or consumption, usually at about 1 lb., then the fingerlings are now ½ lb. Adding fingerlings in the tank that was just harvested will bring you back to where you started: one fish 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-gal tank to a 1500-gal tank. Most commercial aquaponics 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% fish feed costs about \$485 and supplies 305 lbs. of nitrate. A similar amount of nitrate supplied from urea in a hydroponics system costs only \$107. If you plan to run a commercial aquaponics operation, fish must be sold to cover operational costs. Finally, some fish species are poor choices in aquaponics. Examples are catfish, bluegill, and goldfish or any other non-food fish with limited sales outlets. Best choices are tilapia, hybrid striped bass, and rainbow trout in northern climates or as a rotational winter crop with tilapia in summer, and koi, but only where there is a significant retail outlet for large koi.

The clarifier or solid waste filter comes in many shapes and under different names, such as radial filter, swirl filter, solids settling tank, or clarifier. The main function of the clarifier is to separate the solid waste from the nutrient rich water (Figure 6). Most clarifiers rely on reduced water and gravity to settle solid waste at the bottom of tanks to be drained out on a regular basis.

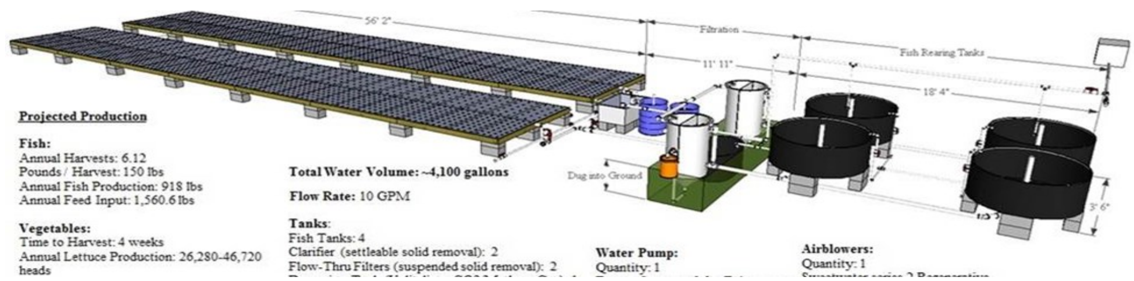

Figure 5. Schematic representation of an aquaponics system

Some systems employ two clarifier tanks in series (Figure 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 disposed of. The solid waste can be aerated for a few days, filtered and the resulting 'compost tea' can be put back in the water of 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 (Figure 8).

The biofilter is where large populations of nitrifying bacteria are housed on inert media with high surface area. The biofilter is the major site of conversion of ammonia to nitrites and nitrates. There are many approaches to building a biofilter as long as there is a very large surface area of inert media in contact with the water. There are also numerous biofilters available commercially. Ammonia conversion becomes more efficient with every increase of surface area provided by the media. Nylon or PVC bird netting, lava rock, polyethylene filter pads, biomatrix pads, polyester filter fiber, floating or sinking plastic beads, fine-pore porcelain, and various other plastic media including bio-balls, bio-barrels, bio-stars, and bio-tubes are commonly used. Once the system is operational and has 'matured', nitrifying bacteria can be found on every inert surface exposed to sufficient oxygen and little organic debris, including the growing troughs, attached to 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 are available that combine the clarifier and biofilter in a single unit, although it is preferable to keep solid wastes separate from areas containing nitrifying bacteria. Some operations use a media bed as a bio-solid digestion (Figure 9). Media beds can be planted also so as not to waste valuable space.

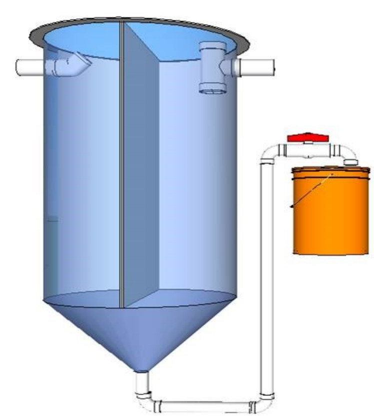

Figure 6. Schematic diagram of a clarifier tank for solid waste separation

The base-additional tank serves the purpose of an addition point to add water amendment products when adjusting the pH of the aquaponics system. The alkalinity and pH of water in an aquaponic system tends to decrease over time due to consumption of utilization of carbonates during bacterial processes and plant growth. Decreases in pH can be rapid, especially after a rain event adds a large volume of water to the system. The water pH should be checked regularly and adjusted by adding a base to bring the pH as close to neutral, pH=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. Crushed oyster shells, a form of calcium carbonate, are also popular among small-scale operations or with homeowners. Oyster shells in a mesh bag submerged in the tank will act as a buffer and slowly and continuously adjust the water pH, but may not be sufficient alone.

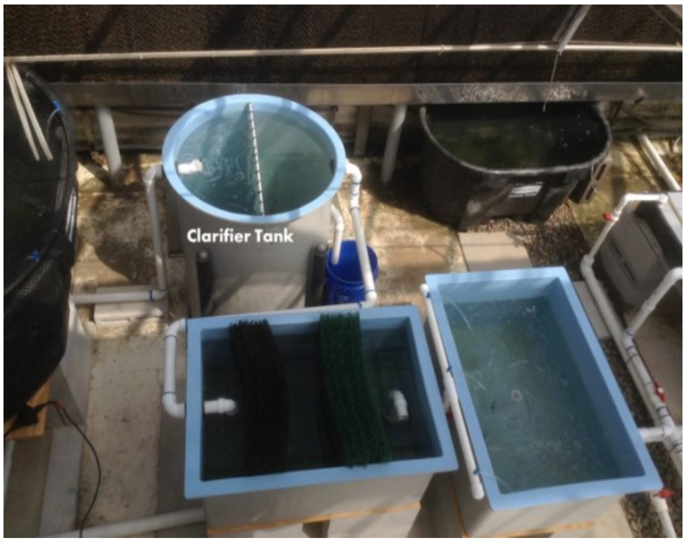

Figure 7. Two clarifier tanks connected in series. First one relies on

Growing troughs or tanks are where plant production occurs. There are currently three types of troughs used in aquaponics. Media beds are filled with a media, such as expanded clay pellets or pH neutral rock, and are usually operated using the flood and drain method (Figure 10). The media bed is set to fill with water during a 20 minute interval, then a float-valve, inverted siphon, or other drain mechanism is activated and the water is drained over a 10 minute interval. This continuous flood and drain cycle guarantees the plant roots never become too dry or wet for too long. Expanded clay is expensive and many growers try to use other material like pea gravel or crushed granite. It is important to use pH neutral rock alternatives. To test if the rock is pH neutral, add vinegar t a small amount of rock and if it starts bubbling, the rock is not suitable for an aquaponics system no matter how well it is washed before use.

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

The advantage of a media bed is that larger plants or fruiting vegetables can be grown in this media. The expanded clay acts as a physical support for the roots of those large plants. The disadvantage of media beds is that large areas can become clogged creating anoxic areas, so frequent cleaning of the media is often required.

Figure 9. Media bed for solid waste filtration

The second type of growing trough uses the nutrient film technique (NFT) currently adopted in hydroponics operations. PVC pipes, gutters, or similar material can be used for system construction (Figure 11). In this system, a thin layer of water is continuously running through the pipes and the plants roots are continuously 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 easily due to smaller volumes and thin sheets of water. However, with the addition of water chillers, lettuce production using NFT can be done year round.

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

The third and most popular type of growing trough is the deep water raft culture system or DWRC (Figure 12). In this system, a rigid closed-cell foam board floats on the surface of relatively deeper troughs that are continually filled with water, and started plants are placed into holes in the foam board so the roots are submerged in water. Supplemental aeration from air stones and an air pump is absolutely vital for the plant troughs in the DWRC system. Troughs can be as shallow as 6 inches and as deep as 24 inches, although 18 inches is the typical standard. Troughs don't 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 11. Various crops grown in a NFT system

In a typical aquaponics system, the fish tanks are the highest point in terms of water level. Water cascades from the fish tank, to the clarifier(s), to the biofilter, to the supplemental aeration tank, to the growing trough (Figure 13).

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

The base addition tank is usually located at or near the return pump at the end of the culture troughs, which is the lowest water level in the system. A water pump is hence necessary to push the water back up to the fish tank. This is normally the only water pump necessary in an aquaponics system, although airlift systems require no pump. Airlift systems utilize the blower supplying air to the fish and plants to return water to the fish tanks. When purchasing a water pump, keep in mind that the flow rating is for a pump pushing water horizontally. If the pump has to push water up or vertically, the flow rating drops significantly. For example, a water pump rated at 500 gph can push water an elevation of 3 ft at 300 gph only. This is why 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 entire system at the total system head a minimum of 3 times per day. For example, in a system with 1000 gallons of water total, and a 500 gph pump pushing 300 gph water up 3 ft of head, you achieve a complete turnover every 3.3 hours, or 7.2 times per day.

An air pump or blower is the only other component utilizing 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 aquaponics system but is of utmost importance, is a backup generator. In case of power outage, plant roots can survive low oxygen levels for about 12-24 hours without significant damage. On the other hand, fish can suffocate in as little as 30 minutes to 4 hours depending on stocking density after a power outage.

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

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 aquaponics system tend to grow faster than in an open field and utilize about 10% 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 are enjoying home-scaled systems for their personal enjoyment and consumption (Figure 14).

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

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