COLLEGE OF AGRICULTURAL, CONSUMER AND ENVIRONMENTAL SCIENCES

Decoupled Aquaponics: A Comparison to Single-loop Aquaponics

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Figure 1. **Example of a single-loop aquaponics system. Fish tanks and filtration components are in the foreground. Texas, USA. (Photo courtesy of R. Shultz.)**

Interest in aquaponics, a food production method that combines aquaculture (the cultivation of aquatic animals such as fish and crustaceans) and hydroponics (the growing of plants in water), is growing globally, and aquaponics systems continue to evolve. Aquaponics combines the cultivation of fish and plants into a recirculating system that uses natural heterotrophic and nitrifying bacteria to convert fish wastes produced in the aquaculture system into plant nutrients for the hydroponic system. For a more complete explanation of the basics of aquaponics, refer to NMSU Extension Guide H-170, *Is Aquaponics Right for You?* (http://aces.nmsu.edu/pubs/_h/H170.pdf). Single-loop (also known as balanced, closed-loop, or conventional) aquaponics systems link the aquaculture component to the hydroponic vegetable component through a single recirculating system (Figures 1 and 2).

Natural decomposing and nitrifying bacteria within the system convert the fish wastes into a nutrient-rich effluent that is cycled into the hydroponic plant unit where the nutrients are taken up by the plants, which purifies the water. The purified water is then returned to the

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Figure 2. **Example of a smaller-scale indoor single-loop system showing the hydroponic portion. Fish tanks and filtration components are in the background. Kentucky State University, USA. (Photo courtesy of R. Shultz.)**

aquaculture tank. Typically, these single-loop systems operate with one water pump. With properly designed and managed systems, only small amounts of water are needed to make up for water losses. As such, these systems use significantly less water than recirculating aquaculture systems, which may require 10% or more of the total volume of water to be discharged and replaced every day, or stand-alone hydroponics systems, which regularly discharge large quantities of nutrient waste solution. In comparison, conventional aquaponics systems only require fresh water to be added to the fish tank to make up for sludge discharge, plant uptake, and evapotranspiration losses (Rakocy et al., 2006).

WHY DECOUPLE AN AQUAPONICS SYSTEM?

Despite the many benefits of single-loop aquaponics systems, there are challenges inherent to these single-loop systems that have limited their ability to scale up to profitable commercial-sized operations. The following challenges have been identified:

- **Water quality conditions:** Aquaponics combines three essential components—plants, fish, and microbes—into one system. Each has its own set of optimal water quality conditions, such as temperature and pH, to achieve maximum production (refer to NMSU Extension Circular 680, *Important Water Quality Parameters in Aquaponics Systems* [https://aces.nmsu.edu/pubs/_circulars/CR680.pdf], for more information). This means that a compromise must be made to achieve overall water conditions that are acceptable to all three components in the same cycling water but suboptimal to each individual component, making it difficult to manage such a system for maximum crop yields.

- **Growing plants with high nutrient demands:** While fish effluent is ideal for growing many vegetative crops, such as lettuce and other leafy greens, concentrations of many nutrients may not be high enough to grow plants with higher nutrient demands, such as fruiting and flowering crops. Fish effluent from a conventional fish feed does not provide all the nutrients required for healthy plant production (Lennard, 2017).

- **Temperature compatibility of species being grown:** A limiting factor with single-loop aquaponics systems is the pairing of cold-water fish species with vegetables that grow best in warm water. Most commodity crops (lettuce, herbs, tomatoes, cucumber, peppers, etc.) grow best between 65 and 80°F, and for this reason many growers couple their crops with tilapia, a warm-water fish. Other producers want to grow higher-value cold-water fish, such as trout, salmon, or walleye, which require much lower temperatures for optimal growth and thereby limit the marketable crops operators can grow and sell.

- **Dealing with system failures:** Another problem with conventional aquaponics systems is that catastrophes like large-scale fish deaths due to disease, water quality issues, power failures, or other technical problems can occur, as can plant diseases or pest infestations. Not being able to disconnect the two components to treat the problems limits treatment options and means that both animal and plant components will be negatively impacted. Even the common practice of adding salt to treat parasitic diseases of fish or to reduce nitrite toxicity would not be possible because this would be incompatible with most plants. An associated issue is that conventional aquaponics systems operate best as they age and accumulate organic acids (humic, tannic, and fulvic) in the water. These acids are known to increase nutrient transport into roots. Restarting aquaponics systems and replacing the water requires an extended period for the organic acids to build up from organic decay in the biofilters.

- **Difficulties obtaining food safety certification:** An additional barrier faced by commercial aquaponics growers relates to difficulties they encounter (due to a lack of understanding of aquaponics) in obtaining food safety certification required by large grocery and restaurant chains because of concerns that fish effluent might carry pathogens that could cause foodborne illnesses. Aquaponics produce and fish have been shown to be safe (Chalmers, 2004), and the risks of pathogenic bacterial contamination have been shown to be far greater in soil-grown produce than in aquaponics produce (Fox et al., 2012). However, despite these facts, food safety concerns and audits that assume that all feces are potentially harmful regardless of source continue to be an obstacle for many commercial growers.

Figure 3. **Hydroponic portion of a decoupled system with supplemental nutrients, combined with triploid Grass Carp in a separate RAS. Alberta, Canada. (Photo courtesy of R. Shultz.)**

Decoupled aquaponics systems (DAPs) offer some solutions to problems inherent to single-loop aquaponics systems. Some of the benefits provided by decoupling the fish and plant systems include:

- Optimal water quality conditions can be provided for the fish and plants without adverse effects to either part, which would increase productivity and yields.
- Each system can be shut down for repairs or if measures must be taken to address disease or pest infestations in either system.
- The hydroponic component can be disinfected, which will increase the likelihood of successfully passing vegetable food safety audits and would expand marketing options.
- Offers the ability to integrate additional units into the system to enhance yields (such as remineralization units and nutrient and pH injectors).
- Mitigates risk in the case of failure of one component.
- Allows nutrient recipes to be tailored to high-demand plants, or nutrient-specific high-value crops.
- Allows cold-water fish production to be combined with warm-water hydroponic plant production.
- Increases the potential for GAP (Good Agricultural Practices) certification by separating the fish and plant components.

Figure 4. **Aerial view of a large-scale commercial decoupled aquaponics operation showing the hydroponics section (left) separated from the fish house (right). Wisconsin, USA. (Photo courtesy of Superior Fresh.)**

HOW DO DECOUPLED AQUAPONICS SYSTEMS WORK?

In single-loop or balanced aquaponics systems, the water from the fish tanks flows through a series of filtration tanks and then into the hydroponic portion of the system. The filtered clean water is then returned to the fish tank via a pump. Aquaponics farms that are designed with the flexibility to decouple the aquaculture from the hydroponic components allow the two systems to be operated independently from one another. While many variations exist, decoupled systems commonly consist of two independent recirculating units: a recirculating aquaculture system (RAS) for fish and a hydroponic unit for the plants (Figure 3). The two systems are connected by a one-way valve that allows flow from the fish tank to a hydroponic reservoir as needed. Decoupling the fish system from the plant system also allows the two units to be housed in separate buildings or greenhouses (Figure 4), which helps eliminate concerns of potential contamination about vegetables with fish effluent.

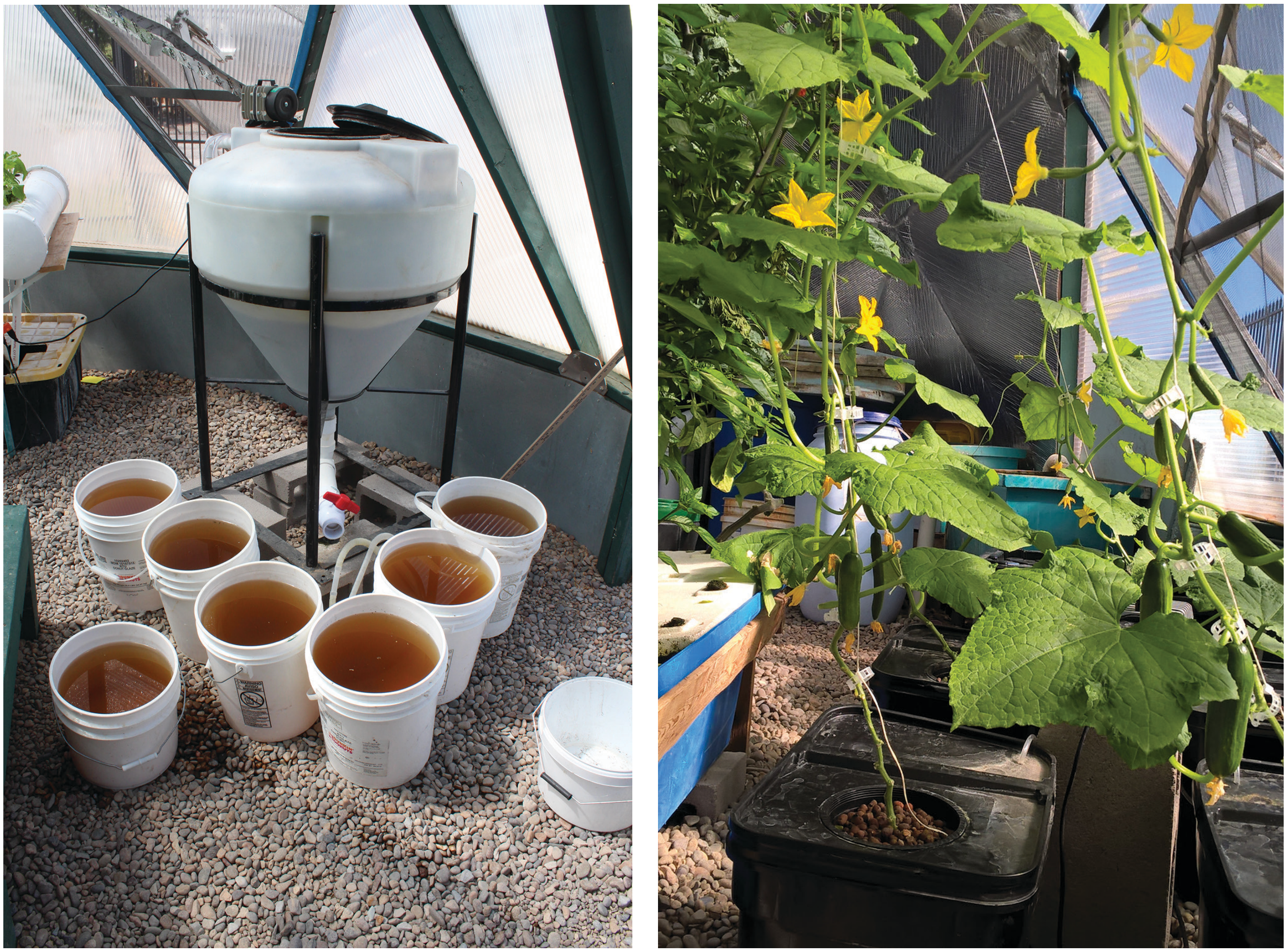
HOW DOES PRODUCTION COMPARE BETWEEN SINGLE-LOOP AND DECOUPLED SYSTEMS?

Although there are few published studies that have conducted side-by-side comparisons of production in single-loop versus decoupled systems (and none at the commercial scale), plant growth advantages of DAPs have been observed in lab-scale experiments. In one study comparing plant and fish yields in a decoupled system to a coupled one and a conventional RAS, the authors reported that fruit yield was 36% higher in decoupled aquaponics, whereas fish production was comparable in both systems (Kloas et al., 2015). This is to be expected since conditions are optimized for plant production and nutrients can be tailored for a specific crop. Fish production would also be expected to increase because optimized environmental conditions for the fish can be provided.

Additional improvements in yield through re-mineralization

Decoupling aquaponics systems also allows fish waste solids discharged from the aquaculture component to be collected and re-mineralized, allowing more nutrients, otherwise bound in the solids, to be made available to the plants. Valuable plant nutrients, such as iron (Fe), phosphorus (P), potassium (K), and calcium (Ca), are released from the fish sludge and subsequently used as a nutrient source for the hydroponic plant component. Preliminary studies indicate that plant growth performance in hydroponic systems can be further improved by providing plants with nutrients acquired by re-mineralizing fish sludge. Aerated or oxygenated sludge is contained in a vessel and continuously mixed to avoid settling (Figures 5a and 5b). Heterotrophic bacteria consume the organic material and eventually release nutrients as dissolved ions. Additional energy is required to aerate and circulate fish effluent during this mineralization process.

The process of re-mineralizing bound nutrients discharged as fish effluent into usable dissolved nutrients is an exothermic process (the reaction releases heat). Therefore, the nutrient solution obtained from the mineralization tank will be warmer than the fish waste that entered the tank. This would allow for the coupling of cool-water fish production with commodity (warm-water) vegetable crops. An additional benefit of this process is that by reusing the fish effluent, the system becomes a zero-discharge facility, thereby reducing its environmental footprint.



Figures 5a and 5b. **Left: Aerobic mineralization tank used to provide dissolved nutrients from fish sludge to hydroponically grown plants. Right: Cucumbers grown entirely on nutrient solution derived from mineralization tank. Santa Fe Community College (SFCC), New Mexico, USA. (Photos courtesy of R. Shultz.)**

DISADVANTAGES/CHALLENGES OF DECOUPLED SYSTEMS

While decoupling aquaponics systems provides solutions to some challenges inherent to single-loop systems, decoupled aquaponics are more complex systems that require greater capital investment, space, technical expertise, and management. For example, because decoupled systems are not continuously recirculating between the two components, it is difficult to provide adequate levels of nutrients for plant growth solely from the aquaculture component. Therefore, hydroponic nutrient salts must be supplemented to the hydroponic tank to compensate for the lack of nutrient buildup, adding costs. On the other side, decoupled systems allow for the addition of mineralization tanks, which can be used in addition to hydroponic nutrient supplementation to provide nutrients for the hydroponic component. Thus, for small-scale production, hobby growers, or systems growing plants with low nutrient requirements like lettuce or herbs, single-loop systems are probably easier to handle and more appropriate and economically feasible. Another option for smaller operations is to incorporate some of the features of decoupled systems, such as adding a mineralization tank, to a single-loop system (Figure 6).

SUMMARY

Interest in aquaponics, a food production method that combines aquaculture and hydroponics in a recirculating system, is growing globally. However,

Figure 6. **Example of a single-loop system in which discharged fish effluent is re-mineralized and returned to the system, allowing for better production of fruiting plants. The blue fish tanks can be seen to the left, and the mineralization tank is in the back. SFCC, NM, USA. (Photo courtesy of R. Shultz.)**

despite the many benefits of aquaponics, there are challenges inherent to conventional single-loop systems that have limited their ability to scale up to profitable commercial-sized operations. These include:

- Maintaining optimal water quality conditions for all three components of the system (plants, fish, microbes) is not possible, so a compromise must be made to achieve overall water conditions that are acceptable but suboptimal, making it difficult to manage such a system for maximum crop yields. Having the same water quality throughout the system also limits which fish and plant species can be combined.

- The inability to disconnect the fish from the plant portions in the event of power failures, pests or diseases in one of the two portions, water quality issues, or other technical issues means both portions can be negatively impacted.

- Difficulties faced by commercial aquaponics growers in obtaining food safety audits required by large grocery chains and restaurant chains because of concerns that fish effluent might carry pathogens that could cause food-borne illnesses.

Aquaponics farms that are designed with the flexibility to decouple the aquaculture from the hydroponic component allow the two systems to be operated independently from one another. Decoupled systems offer solutions to the challenges faced by single-loop systems. Benefits include:

- Optimal water quality conditions can be provided for the fish and plants without adverse effects to either part, which would increase productivity and yields and make possible the production of cold-water fish and warm-water hydroponic plants in one system.

- Each system can be shut down for repairs or if measures must be taken to address disease or pest infestations in either system.

- By decoupling the fish and plant components, hydroponic holding tanks can be disinfected, increasing the likelihood of successfully passing vegetable food safety audits as well as GAP certification, both of which would increase marketing options.

Decoupled systems hold the prospect of eliminating existing barriers to the development and growth of commercially viable, large-scale aquaponics food production systems. However, these more complex systems require greater expertise and capital investments and are probably not necessary or advisable for hobby growers or systems intended for small businesses or educational and outreach purposes.

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