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FEATURES

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Rethinking Aquaponics for Scalable CEA

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Aquaponics is often seen as a hobbyist endeavor or a sustainable growing method used for advancing science in schools, where fish and plants are grown together in a controlled or semi-controlled environment. It's also commonly practiced in low-and middle-income countries or in small to medium-sized greenhouses producing lettuce or other greens alongside tilapia.

A recirculating aquaculture system (RAS) designed to generate nutrients for decoupled and hybrid aquaponics systems.

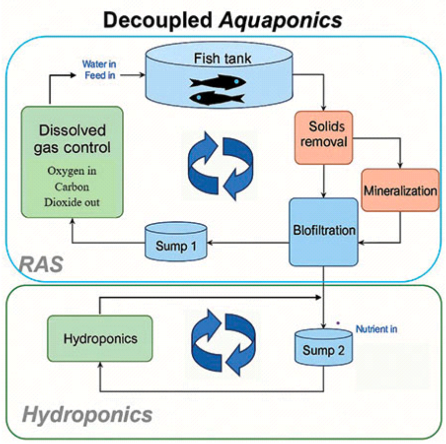
Optimizing design for plants and fish

At its core, aquaponics integrates a recirculating aquaculture system (RAS) with hydroponic plant production. This RAS continuously recirculates and treats water from the fish tanks by incorporating solid waste removal and biofiltration processes into the water flow loop that help maintain water quality for the fish and deliver clean, treated water back into the fish tanks.

Biofiltration essentially refers to the microbial conversion of ammonia (excreted by fish) to nitrate, but also includes the breakdown of dissolved and particulate organic matter into plant-available nutrients. The system water becomes nutrient-rich over time and this effluent can be delivered to traditional hydroponic systems such as floating raft, nutrient film technique (NFT) or media beds.

In coupled aquaponics systems, water circulates in a single loop, with plants serving as an additional biological filter, removing nitrate and reducing ionic loads before the water returns to the fish. In contrast, decoupled aquaponics systems separate the fish and plant loops, allowing environmental parameters such as pH, EC and nutrient concentrations to be optimized independently for plant growth. For commercial-scale operations, decoupled systems are generally recommended and often preferred.

Thinking past leafy greens



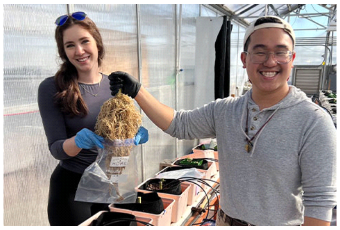
Despite its promise, commercial aquaponics has struggled to become commonplace. Much like Vegas nightclubs, many large commercial aquaponics ventures often shine brightly—then fade after a few years. One high-profile example is Superior Fresh, once the largest aquaponics facility in the U.S., operating 250,000 sq. ft. of greenhouse and producing 1.5 million pounds of Atlantic salmon annually. They recently announced the closure of their aquaponics operations to focus on expanding their land-based salmon production, which has been highly successful.

Decouple aquaponics system diagram.

The economics of aquaponics hinges largely on crop selection. Low-margin crops like lettuce simply cannot offset the higher capital and operational costs of recirculating aquaculture. While small-scale growers can find success selling lettuce and other greens through farmers markets and other local initiatives, those markets are limited and become untenable when trying to scale up. On the other hand, high-value crops such as cannabis, specialty herbs or even saffron and edible flowers present a much more compelling case. These crops not only fetch higher market prices, but their performance can be enhanced by the biological complexity of fish effluent.

A major barrier to broader adoption of aquaponics is the persistent belief that it's too complicated or only suited for hobbyists or classrooms. This perception has hindered both investment and innovation in the field. However, with advancements in system design, automation and nutrient modeling, aquaponics is increasingly becoming a viable method for producing high-value crops at scale. The problem isn't that aquaponics doesn't work, it's that the tilapia-and-lettuce model doesn't scale profitably. Neither lettuce nor tilapia have high enough value to justify the infrastructure costs, even if both are grown successfully.

Getting into the details



Two key questions remain regarding aquaponics: Why does aquaponics work? And why isn't it more profitable? The answer is actually much less nuanced than one might think.

Graduate student Lauren Stevenson (left) and undergraduate researcher David Dong (right) display roots from a hemp plant that was grown using a hybrid aquaponics model, demonstrating the visible microbiome on the roots.

From a CEA perspective, aquaponics works because fish waste contains all the macro- and micronutrients that plants require to grow. Fish also excrete ammonia through their gills, which is converted to nitrate by nitrifying bacteria in biofilters. These bacteria are naturally occurring and will colonize high-surface area biofilter media in the presence of ammonia to efficiently convert toxic ammonia into nitrite then nitrate. The process is well understood and can be modeled based on fish feed input and its protein content, allowing growers to predict nitrogen output and match it to the needs of lettuce or other leafy greens.

Ironically, this linear way of thinking often leads commercial aquaponics businesses to failure. Lettuce may be easy to model, but its low market value on a large scale makes it difficult to cover aquaculture's high overhead.

So why don't more aquaponics businesses grow high-value or fruiting crops? This is where maintaining nutrient balances becomes a major challenge. Commercial fish feeds aren't designed with plant nutrition in mind and no aquaponic-specific feed currently exists (R.I.P. Optimal Aquafeed) to optimize downstream nutrient profiles. Despite an aquaponic fish feed not being currently available, the quality and brands of fish feed being used in aquaponics systems are important and progress is being made to enhance nutrient concentrations.

Unlocking nutrients through mineralization

At the University of Arizona's Controlled Environment Agriculture Center (CEAC), we're actively working to solve these challenges and better understand the nutrient dynamics in aquaponics systems. We've found that it takes time to build up nutrient concentrations that support high-nutrient demand crops such as tomatoes or cannabis to where we're able to produce equal yields as with hydroponics. To do this, we collect and mineralize our solid fish waste through aerobic digestion, releasing bound nutrients, which we then reintroduce back into the system.

Hemp plants in early flower phase growing in Dutch buckets. The left row of plants utilizes a hybrid approach with 10% aquaponic effluent, while the row on the right is hydroponically grown.

A recent pilot study showed this approach boosted macro nutrients like calcium and potassium by 25% to 40% and several micronutrients by nearly 100% or more. Without this mineralization step, it's difficult to achieve success on a commercial scale and "free money" in the form of nutrients is left on the table.

While our nutrient levels are comparable to your average hydroponic recipe, we also obtain additional benefits from the aquaculture effluent. For instance, we consistently achieve comparable yields to hydroponically grown cannabis, while realizing 35% to 55% water savings. More importantly, we've shown that aquaponic effluent supports a more diverse and functional root microbiomes, including numerous plant growth promoting microbes. We believe that this microbial consortium is the key and major advantage of aquaponics that truly makes it a more sustainable growing method.

A hybrid approach for modern CEA

The goal was never to convince hydroponic farmers to convert their operations to aquaponics; instead, our aim has been to explain how hydroponics could benefit from aquaponic innovations. Therefore, we made it our mission to understand this microbiome benefit and how we might transfer it into hydroponics systems. What we've found so far is that by mixing 10% aquaculture effluent directly into a top drip Dutch bucket hydroponic system, we're able to successfully transfer certain microbes from the aquaponics system into the root zone of plants and reduce water usage by >35% while delivering the same (or better) yield.

While our early work focused on cannabis, we're now testing this method on vining crops and ornamentals. The model offers hydroponic growers the biological benefits of aquaponics without having to invest in large-scale aquaculture infrastructure or the expertise required to run and manage these systems.

To be viable on a large scale, aquaponics must focus on high-value crops, such as cannabis, or be operated as hybrid formats like those we've developed. By emphasizing the biological and sustainability benefits and minimizing operational barriers, aquaponics is poised for a more impactful role in commercial CEA.

Looking ahead, the integration of aquaponics into mainstream horticulture will likely accelerate as growers face increasing pressure to reduce water use and chemical inputs. As our understanding of plant-microbe interactions deepens, aquaponics may evolve from a niche to a cornerstone of regenerative indoor agriculture. Continued research will further validate its benefits, particularly around microbiome enhancement and resource efficiency. For growers curious to explore these synergies, pilot systems or hybrid approaches offer a low-risk entry point with potentially high rewards.

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