



Decoupled Aquaponics Systems: Advancing Sustainable Fish and Vegetable Production

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Abstract

Unlike the main constraints of conventional coupled aquaponics systems, decoupled systems allow aquaculture and hydroponic systems to be operated in separate loops where nutrients are carried in a single direction. Decoupled configurations help to mitigate the pH compromise that can restrict the bioavailability of nutrients for plants, enable targeted fertilizer supplementation while keeping fish exposed to no chemicals and provide biosecurity benefits through isolated disease management. However, decoupled systems require greater capital investment, more complex infrastructure and advanced technical management and they interrupt reciprocal microbial exchange between fish and plant components. Some potential research areas for the future involve implementation of sludge remineralization for nutrient recovery, advanced water conservation technologies like atmospheric water harvesting and incorporation of IoT and AI for automation and water precision control. Systematic standardization and ongoing innovations suggest that decoupled aquaponics may provide a viable, resource-efficient platform for multifunctional and sustainable fish-crop production systems in a variety of agro-climatic conditions and, interestingly, be scaled up to support commercial applications.

Keywords: Aquaponics, Decoupled aquaponics system, Filtration, Hydroponics, Nutrients

Introduction

Increased food production is required worldwide for future global food security and sufficiency, especially because of global population growth. However, the expansion of conventional agriculture is increasingly limited by its lack of access to sufficient fresh water and the degradation of soils and loss of agricultural land. Hydroponic or soilless plant cultivation is a way of achieving high crop productivity with significantly reduced water consumption when compared with soil-based cultivation (Nath and Datta, 2022). Nevertheless, its dependence on external mineral fertilizers, particularly nitrogen, increases production costs and raises

sustainability concerns. Meanwhile, growing demand for fish and other aquatic foods is driving the aquaculture sector to become more productive and eco-friendly. The fish's excreted waste and the feed that is not eaten create a great deal of waste in the water, which, when not managed properly, can lead to rapid deterioration of water quality. The recovery and use of these nutrients have the potential to improve resource-use efficiency in aquaculture and crop production systems.

Aquaponics is an innovative farming technique in which fish farming is performed in a recirculating aquaculture system (RAS) and plants are grown in a soilless hydroponic

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unit (Monsees *et al.*, 2017). Typical installations consist of fish tanks, mechanical and biofilters and hydroponic growing beds. Fish are reared in well-aerated tanks fed with commercial feeds, resulting in the generation of effluents containing high levels of suspended solids and dissolved nitrogenous waste. These effluents undergo mechanical filtration before being subjected to biological filtration, where nitrification of ammonia into nitrate is carried out by nitrifying bacteria. The nutrient-rich water is then fed to hydroponic beds where plants utilize available nutrients and help to improve water quality before returning to the fish culture tanks. This permanent recirculation allows for the combination of fish and plant farming and promotes nutrient recovery and water reuse (Figure 1).

Need for Decoupled Aquaponics Systems

Conventional aquaponics usually works in a closed or coupled system where water continuously flows through the fish culture tank, filtration system and hydroponic growing beds. The primary benefits of this arrangement include its simplicity, less infrastructure (fewer pumps and tanks) and less advanced management skills. Coupled aquaponics improves resource efficiency over aquaculture and hydroponics by recycling water and recovering nutrients from aquaculture effluents.

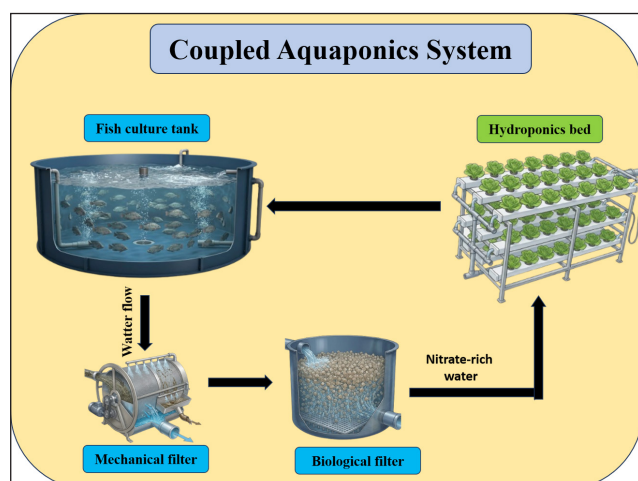


Figure 1: Schematic diagram of a coupled aquaponics system (adapted from Lobanov *et al.*, 2026)

But this is a shared-water design that has many biological and operational limitations. Fish, plants and nitrifying bacteria must all function under the same water-quality conditions, even though their optimal requirements differ markedly. Most vegetable crops grow best under more acidic conditions, pH 5.5-6.5, while nitrifying bacteria are most active at near-neutral to slightly alkaline pH 7.0-8.0 and most fish species prefer near-neutral to slightly alkaline pH (6.5-7.5). Hence, in most cases, the coupled systems are run at a pH of compromise that is neither too high nor too low. This compromise can limit production potential for fish, plants and microbial communities.

The common water loop makes disease and pest control difficult too. An applied fish treatment such as a salt, antibiotic, or disinfectant may have a negative effect on the plant or beneficial nitrifying bacteria; plant protection

chemicals can negatively affect fish and microbial biofilters. Furthermore, crop productivity in coupled systems can be limited by the nutrient composition of fish feed and the resulting effluent. Wastewater might not provide sufficient levels of plant nutrients, such as potassium and some micronutrients, to support plant growth and production. Biological and managerial restrictions can limit the flexibility of the operation, limit the productivity of the crop and restrict the potential for commercialization of coupled aquaponics systems.

Decoupled aquaponics has become an alternative design that is gaining research interest due to these challenges (Mourantian *et al.*, 2025). In decoupled aquaponics, the recirculating aquaculture system (RAS) and the hydroponic subsystem operate as separate loops. Processed aquaculture effluent is pumped into the hydroponic subsystem in a unidirectional fashion, on demand, where plant roots take up the available nutrients. Water from the hydroponic subsystem is not returned to the fish culture tanks, allowing water quality, pH, temperature and nutrient regimes to be optimized independently for fish and plants.

Components and Working Mechanism of a Decoupled Aquaponics System

A decoupled aquaponics system has several components: fish culture tanks, mechanical and biological filtration units, separate sump tanks for the fish and plant systems and hydroponic growing beds (Figure 2). The water from fish culture tanks will have suspended solids and dissolved nitrogenous wastes. This effluent is first passed through mechanical and biological filters, which filter out solids and convert ammonia to nitrate by nitrification. Following filtration, a portion of the treated effluent is directed to the plant sump tank, while the remaining water is transferred to the fish sump tank.

The fish sump tank maintains proper water quality by aerating, degassing and disinfecting the water, if needed, before recirculating it to the fish culture tanks. In the meantime, essential nutrients, mineral supplements, pH modifiers, or other plant-specific inputs can be added to the plant sump tank according to the plant's needs. The nutrient rich solution is then pumped to the hydroponic growing beds where the plants take in the nutrients provided for growth. In contrast to coupled aquaponics, the water recirculated in the hydroponic subsystem is not used for rearing the fish. As a result, plant uptake, evapotranspiration and other system processes reduce water levels, so the system must be replenished for continuous operation. This separation facilitates the independent management of the fish and plant subsystems and can help to optimize the water quality and nutrient conditions for each culture unit.

Advantages and Limitations

Decoupled aquaponics eliminates the pH compromise associated with coupled systems, which typically operate at an intermediate pH of approximately 7.0. At this pH, the availability of nutrients such as phosphorus, iron, potassium, calcium and manganese to plants may be reduced. By allowing independent pH regulation, the plant loop can be

maintained at approximately 5.5-6.0 to improve nutrient solubility and uptake, while the pH in the fish and biofilter loops can be suitably adjusted for the fish and nitrification processes. Aquaculture effluent is usually high in nitrogen and phosphorus and low in potassium, as well as in minerals such as iron, calcium, magnesium and zinc, so decoupling allows for targeted and targeted dosing of mineral fertilizers straight to the plant loop without adding excessive amounts of the nutrients to the water for the fish and beneficial microbes. This independent management of pH and nutrients has been demonstrated to significantly improve crop yields, for instance, by 36% higher tomato fruit yield for the decoupled versus coupled aquaponics as shown by pilot studies (Monsees *et al.*, 2017). In addition, decoupled systems are more efficient when it comes to resources, as up to 30% less energy is consumed than in a conventional hydroponic greenhouse (Körner *et al.*, 2021). Furthermore, because of the separation of the aquaculture and hydroponic loops, biosecurity and disease management are enhanced by reducing the potential for system-wide failures and fish treatment (*e.g.*, salts, formalin) and plant-protection treatments (*e.g.*, fungicides, pesticides) can be applied independently without cross-toxicity, making decoupled aquaponics a flexible, productive and commercially viable integrated aquaculture - crop production platform.

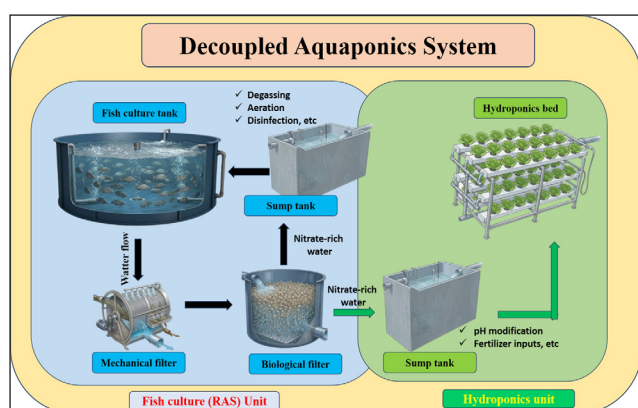


Figure 2: Schematic diagram of a decoupled aquaponics system (adapted from Mourantian *et al.*, 2025; Lobanov *et al.*, 2026)

Despite these advantages, decoupled aquaponics is more expensive because of the requirement for multiple plumbing loops, pumps, filters, sumps and monitoring devices. This extra infrastructure will have an impact on the physical footprint and may decrease the space available for crop production. Water moves unidirectionally in one direction from the aquaculture system to the hydroponic system, so each of these subsystems will typically need to be fed new water independently and each may produce an aquaculture and hydroponic waste stream, contributing to a higher water demand and treatment needs.

Furthermore, the effluent from the aquaculture system might not provide all the nutrients required for plant growth, thus requiring additional nutrient inputs for fertilization and increasing production costs. The independent loops also require constant monitoring of the pH, electrical

conductivity, dissolved oxygen and temperature; this will require higher technical skills and more intensive management. Furthermore, by decoupling, microbial exchanges between the fish and the plant subsystem are interrupted and the consequences for microbial stability over the long term, the remineralisation of sludge and pathogen suppression have yet to be fully understood.

Future Scope

Decoupled aquaponic systems have significant potential for further improvement in nutrient recovery, water management, automation and system integration. Remineralization of fish sludge with high amounts of organic matter and bound nutrients is one of the most important research areas. It may be possible to combine aerobic mineralization reactors and anaerobic digesters into the system to break down organic wastes and release nutrients in plant-available forms. This mineral-rich solution could be used in the hydroponic fertigation system, which would decrease the need for synthetic fertilizers and enhance nutrient-use efficiency. But further research is required to optimize mineralization conditions, nutrient recovery rates and the safe application of recovered nutrients to crops.

Water conservation is also an area of further study that is critical, especially in arid and semi-arid areas. Water from the hydroponic subsystem is not recycled back to the fish culture unit, which could increase freshwater needs due to evapotranspiration and other system losses. Water vapour from plant evapotranspiration can be collected in greenhouses using cold-trap air-conditioning condensers and used in the aquaculture loop.

Smart aquaponics systems also have a lot of opportunities. Real-time monitoring of the various parameters, including pH, electrical conductivity, dissolved oxygen, temperature and nitrogenous compounds, can be achieved from different fish and plant loops through the use of IoT-based sensor networks. If combined with automated control units and predictive models, these systems could allow more accurate dosing of fertigation, nutrient characterization and water quality management according to the growth stages of the crops. But under real production environments, the reliability, cost-saving and energy consumption of these technologies should be carefully evaluated.

Conclusion

Finally, decoupled aquaponics provides an alternative approach to integrated fish and crop production with independent management of the aquaculture and hydroponic subsystems. This allows for fewer compromises in water quality and nutrient management, thus providing opportunities to enhance production efficiency and crop performance. However, issues of high infrastructure cost, water demand and complexity still exist. Further studies are needed on nutrient recovery, water recycling, system automation and standardization and these topics have to be explored to progress the use of decoupled aquaponics as a viable and sustainable food production technology.

References

- Körner, O., Bisbis, M.B., Baganz, G.F.M., Baganz, D., Staaks, G.B.O., Monsees, H., Goddek, S., Keesman, K.J., 2021.

- Environmental impact assessment of local decoupled multi-loop aquaponics in an urban context. *Journal of Cleaner Production* 313, 127735. DOI: <https://doi.org/10.1016/j.jclepro.2021.127735>.
- Lobanov, V., Monsees, H., Latrille, F., Pate, J., Joyce, A., 2026. Coupled vs. Decoupled aquaponics: Evidence, mechanisms and methodological gaps in the productivity hypothesis. *Aquacultural Engineering* 115, 102781. DOI: <https://doi.org/10.1016/j.aquaeng.2026.102781>.
- Monsees, H., Kloas, W., Wuertz, S., 2017. Decoupled systems on trial: Eliminating bottlenecks to improve aquaponic processes. *PloS one* 12(9), e0183056. DOI: <https://doi.org/10.1371/journal.pone.0183056>.
- Mourantian, A., Aslanidou, M., Mente, E., Katsoulas, N., Levizou, E., 2025. Capturing the physiological and growth dynamics of cucumber cultivated in coupled and decoupled aquaponic systems. *Scientia Horticulturae* 351, 114377. DOI: <https://doi.org/10.1016/j.scienta.2025.114377>.
- Nath, M.K., Datta, H.S., 2022. Advances in Indian floriculture with focus on the North-East region. *Research Biotica* 4(3), 108-112. DOI: <https://doi.org/10.54083/ResBio/4.3.2022/108-112>.