

The Role of “Aquaponics” in Recirculating Aquaculture Systems

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ABSTRACT

Recirculating aquaculture systems (RAS) are designed to recondition “used” fish water so that it can be recycled back into the fish-rearing tank(s). These systems have become popular because of the ability to control water parameters, their high-density rearing capabilities, and their potential for water conservation. Because of the accumulation of nutrients in these systems, they offer an underutilized resource for persons willing to transform an existing RAS into one that integrates plants. A secondary crop of plants can add to the system’s profit, with little overhead cost. The reduction of certain nutrients by the plants can also benefit the system by reducing or eliminating expensive filtration components. These integrated systems have gained recognition by researchers and commercial users alike, and have stimulated the interest of many because of their resource-efficient and “eco-friendly” status.

INTRODUCTION

Various types of intensive and extensive integrated fish/plant systems have been well documented and described. These include: utilization of wetlands for treatment of fish effluents (Schwartz and Boyd 1995),

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use of seaweeds for removal of nutrients from mariculture (Troell et al. 1999), irrigation of field crops (McIntosh and Fitzsimmons 2003), and aquaponics (Rakocy et al. 1992). Aquaponics is the integration of growing plants (hydroponically) and fish (aquaculture) in one system, usually in a recirculating system. In RAS that have a daily water exchange of less than 5%, nutrient concentrations approach levels found in commercial hydroponic solutions (Rakocy 2002); this makes an ideal situation for an integrated fish/plant system.

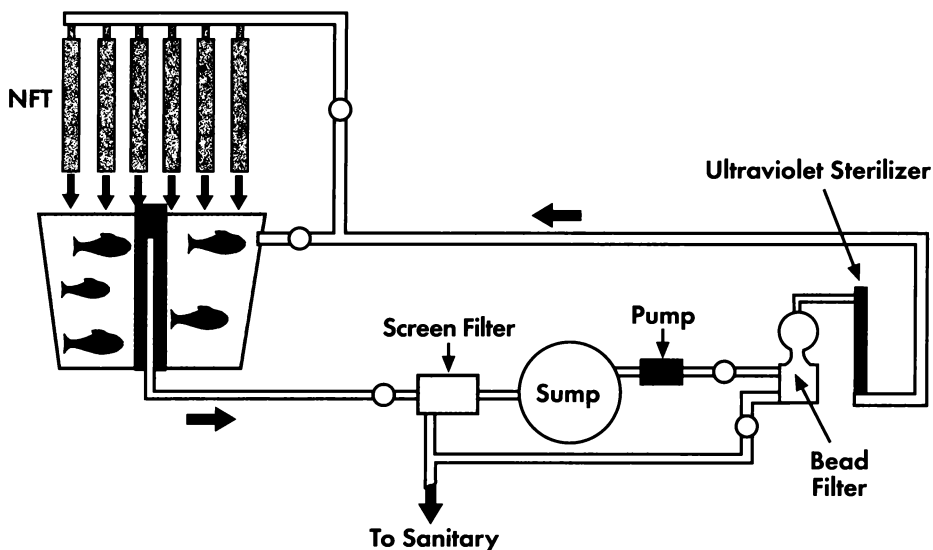
Recirculating aquaculture systems have many water treatment options available in their set-up. These may include: mechanical filtration, biological filtration, ultraviolet sterilization, ozonation, aeration, carbon filtration, or any combination of these steps. Various components of RAS, as well as numerous system configurations have been documented (Wheaton 1977, Piedrahita 1991, Lawson 1995, Summerfelt *et al.* 2001, Timmons *et al.* 2002). Total recirculating systems typically reuse 95-99% of the system water, while partial recycle systems reuse 50-85% of the water (Summerfelt *et al.* 2001). A daily water loss may be necessary due to filter maintenance and removal of nitrates (NO_3^-) (Lawson 1995).

Nutrients from fish wastes have the potential to become a nutrient source for the plants and thus are considered a valuable resource in an integrated system (Chamberlaine and Rosenthal 1995). This practice can be advantageous because, in addition to reconditioning the water, it has the potential to create a more cost-effective operation than a single-crop system. There are also many advantages of growing plants in an indoor recirculating system. These include: the elimination of soil-borne pathogens, controlled environment leading to increased harvests, and water conservation (Jones 1997).

System Requirements

Because of the various components available in aquaculture and hydroponics, the design of an integrated system is somewhat subjective to the grower. However, there are general recommendations for designing the filtration process for an aquaponic system. Rakocy (2002) points out that the design of an aquaponic system is based on the design of the RAS with the addition of a hydroponic component (Figure 1). The optimal arrangement for this would include: a fish rearing tank, a solids removal device, a biofilter, and a hydroponic system (Rakocy 1999).

Figure 1. Schematic of an aquaponic system using the nutrient film technique (NFT) for growing the plants.



Aquaponic systems vary in the techniques used for the removal of settleable solids (Table 1). The technique used for solids removal is probably the most subjective process in both research and commercial systems. These options include: immediate removal by screen filters; intermediate removal by settling tanks, sand filters, bead filters, and cartridge filters; and gradual removal by natural decomposition (gravel/sand beds). There are many variables involved in choosing the optimal solids removal device. Daily feed input, plant species, and the size and type of plant growing area should all be considered in this decision process (Rakocy 2002).

The biofiltration of importance to aquaculture systems is nitrification. This process uses beneficial autotrophic bacteria to oxidize ammonium (NH_4^+) to nitrite (NO_2^-) and later to nitrate (NO_3^-) (Wheaton 1977). The primary biological filter (biofilter) may be located prior to the plant growing system, or the plant growing system itself may serve as the biofilter. The type of plant rearing system used will determine if additional biological filtration will be needed. Each plant growing technique provides a different amount of surface area needed for the colonization of beneficial nitrifying bacteria. Rakocy (1999) found that

Table 1. Various components and processes used in research and commercial aquaponic operations.

Reference	Research/ Commercial	Solids Removal	Bio- filtration	Plant System
Rakocy <i>et al.</i> 1997	R/C	Clarifier/ settling	Plant system	Floating raft
McMurtry <i>et al.</i> 1997	R	Sand beds ^a	Sand Beds	Sand beds
Adler <i>et al.</i> 2000	R	Settling tank	Fluidized bed	NFT
Seawright <i>et al.</i> 1993	R	Clarifier	Trickle filter	Floating raft
Harmon 2003	R	Bead filter	Bead filter	NFT
Sutton and Lewis 1982	R	Sedimentation	Three compartment	Gravel beds
Weaver and Shaw 2000 ^b	C	Drum filter	Bead filter	Floating raft
Smith 1993 ^c	C	Gravel beds ^a	Gravel Beds	Gravel Beds
Wilson 2002 ^d	C	Screen filter	unknown	NFT
Nelson 2000 ^e	C	Gravel Beds	Gravel Beds	NFT

^a same unit serves as surface area for all three processes

^b Integrated Aquatics, Welcome, Ontario

^c S&S Aquafarms, West Plains, MO

^d Tailor Made Fish Farms Pty Ltd., Australia

^e Future Aqua Farms Ltd., Chezzetcook, NS

when correct ratios of fish feed to plant growing area are used in raft hydroponic systems, sufficient nitrification is possible, whereas nutrient film technique (NFT) systems may require additional biofiltration.

A large ratio of plant growing area to fish growing area is needed to achieve a balanced system, but can vary from 2:1 to 10:1 depending on the system (Rakocy 1999). In a properly designed system, a small amount of fish can support a large number of plants. However, aquaculturists may

not necessarily want to maximize plant production, but only use them to supplement existing income and/or as tertiary filtration. Ultimately, it is the input of fish feed that determines the quantity of plants that can be successfully grown in the system. Rakocy (1992) found that lettuce production in a raft system was maximized with a daily feed input of 2.4 g/plant/day while Harmon (2003) found that 1.3 g/plant/day was sufficient for lettuce production in a NFT system.

In aquaponic systems, beneficial (nitrifying) bacteria, fish and plants all differ in optimal pH levels. Most literature shows that optimal pH for nitrifying bacteria (*Nitrosomonas* sp. and *Nitrobacter* sp.) is 7.8-9.0 (Hochheimer and Wheaton 1991). A typical hydroponic nutrient solution has a pH of 5.0-7.0, and it is known that plant growth may be affected if the pH is outside of this range (Jones 1997). Therefore, aquaponic systems should maintain a pH at or near 7.0 to meet the needs of the entire system.

Nutrient Removal

Most nutrients become available to plants after the decomposition of fish wastes. Many nutrients that accumulate in RAS do not have adverse effects on the fish, and in typical RAS are not utilized. However, a few of these can be of potential concern for fish culturists if they reach elevated levels. Un-ionized ammonia (NH_3) is toxic to fish at very low levels (Meade 1985) and is considered to be a limiting factor in high-density culture conditions. Phosphorus (P) and nitrate (NO_3^-) levels may also be a concern for some culturists as they may be monitored by regulatory agencies if the fish culture effluent is being discharged into surface waters. Plants have the ability to absorb ammonium (NH_4^+), phosphate (H_2PO_4^-), and nitrate (NO_3^-) ions, and therefore, are beneficial in the removal of these from the system. This situation makes for an ideal symbiotic relationship between the fish and plants.

Nutrient removal rates vary according to plant species, system design, and quantity of plants. Rakocy *et al.* (1997) recorded a 51% reduction in total ammonia nitrogen (TAN) and 38% nitrite (NO_2^-) reduction after flowing through a raft hydroponic system. Adler (1998) recorded a 99% reduction of dissolved phosphorus and a 60% reduction of nitrate concentration after flowing through a NFT conveyor system. Gloger *et al.* (1995) recorded a 24% reduction in total dissolved solids (TDS) in a lettuce raft culture system. Troell *et al.* (1999) found that in a mariculture system, *Gracilaria* sp. could remove 50-95% of the dissolved ammonium.

Plant System

Most hydroponic growing methods can be used in aquaponic systems (Table 1). Depending on the system, not all the fish culture water may be required to flow through the plant growing system. This will depend on the primary purpose for the plants in the integrated system as well as the size and type of the plant growing system. The plant growing system is usually the last component in an aquaponic system. Some systems utilize the hydroponic growing area (gravel/sand beds) as a means of mechanical filtration, while others do not rely on the use of the plant growing area as a solids filtration component (Table 1). In systems where the plant beds are also used to remove fish wastes, careful consideration must be given towards the accumulation of fecal matter vs. decomposition rate. These growing beds can easily become clogged and become anaerobic due to the rate of solids accumulation. However, it may be beneficial for some of the suspended solids to accumulate in the system and undergo decomposition to allow for mineralization of nutrients (Rakocy 1999).

Nutrient Supplementation

Typically, lettuce and herbs grow well with little or no nutrient supplementation to the aquaponic system. However, nutrient deficiencies do differ among systems, depending upon fish feed, feeding rates, plant species, filtration techniques, and the substrate in which the plants are grown. Nutrient concentrations must be monitored on a regular basis due to the possibility of nutrient deficiencies and salt accumulation (Seawright et al. 1998). Rakocy and Hargraves (1993) provide a good overview of nutrient supplementation for various crops in integrated systems.

The most common additions to a lettuce or herb aquaponic recirculating system include: chelated iron (Fe), potassium hydroxide (KOH), and calcium hydroxide (Ca(OH)₂). Because the required quantities of iron are not found in most aquaponic systems, a source must be added to the system on a regular basis. Iron is generally added to achieve a 2 mg/L concentration. Rakocy *et al.* (1997) added iron every three to four weeks for a lettuce crop, while Harmon (2003) added iron biweekly for a four-week crop of lettuce (2x per crop). The pH in RAS will decrease due to carbonic acid that is produced during the nitrification process (Wheaton *et al.* 1991). Therefore, it is necessary to make pH adjustments accordingly. Calcium hydroxide and potassium hydroxide provide a method of increasing pH as well as a source of calcium and potassium,

which are vital nutrients for plants and are often not found in the desired quantities for aquaponic systems (Rakocy *et al.* 1992).

CONCLUSION

Aquaculturists have the advantage over horticulturists in retrofitting an existing growing system into an integrated one. In an existing RAS, the requirements for an integrated system include: the plant growing system, minor modifications to the already existing filtration system, and the additional knowledge of hydroponic growing techniques. However, in an existing horticulture setting, all the RAS components, including fish, are required to set-up an aquaponic system. Generally, this is not feasible due to the large capital expense for filtration as well as extended knowledge of aquaculture and animal health.

The profit generated from plants would be determined by the plant species, growing system, and market prices. Adler *et al.* (2000) concluded that an integrated trout/basil operation could generate profit. Bailey *et al.* (1997) also determined that aquaponic farms in the U.S. Virgin Islands could be profitable. In an integrated system, the plant growing costs would be much less than in a commercial hydroponic operation because of the polyculture situation. If the operation is an existing aquaculture operation, the operating costs would be virtually unchanged or even reduced if it were converted into an aquaponic operation. This is providing that the additional space required for expansion is currently available. The second crop can also serve as an economic buffer if the market value of one crop declines or becomes a marketing issue. As with any type of farming enterprise, many variables should be considered when creating a business plan. Furthermore, in all aquaponic operations the grower must be well versed in all aspects of hydroponics and aquaculture. The knowledge of pests and disease in fish and plants and the toxicities associated with the supplementation of nutrients is critical to a successful aquaponics operation.

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