A Prototype Recirculating Aquaculture-Hydroponic System

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Abstract

A prototype recirculating aquaculture-hydroponic system was developed to illustrate one of the many engineered production systems used in modern agriculture. The system provides an artificial, controlled environment that optimizes the growth of aquatic species and soil-less plants, while conserving water resources. In this system, fish and plants are grown in a mutually beneficial, symbiotic relationship. Suggestions for using the system to integrate the teaching of math, science and technology principles are provided.

Introduction

Recirculating aquaculture-hydroponic systems are designed to provide an artificial, controlled environment that optimizes the growth of fish (or other aquatic species) and soil-less plants, while conserving water resources (Rakocy and Hargreaves, 1993). In such systems, the fish and plants are grown in a mutually beneficial, symbiotic relationship. Un-ionized ammonia-nitrogen is produced as an intermediate by-product of protein metabolism by the fish and high concentrations of this nitrogen can cause mortality. However, some forms of nitrogen can be used as a plant nutrient, and are removed from the water by the plant roots as the water circulates through the hydroponic unit. Thus, a harmful by-product of fish production becomes a beneficial input for plant production (Rakocy, Hargreaves and Bailey, 1993).

Purpose

This project sought to develop a low cost recirculating aquaculture-hydroponic system suitable for use in laboratory settings. A secondary purpose was to identify educational activities which use the system to teach science, math and technology principles.

Aquaculture-Hydroponic System Design and Construction

As shown in Figure 1, the primary system components include the fish culture tank, a water treatment tank, a packed column aerator, and the hydroponic unit. Auxiliary components include a drain tile (with clean-out access),an air pump and bubble wand, a submersible pump, submersible electric water heaters, and water lines.

The aquaculture-hydroponic system can be constructed for approximately $600 from readily available materials. A bill of materials and an approximate cost breakdown for the system is presented in Appendix One.

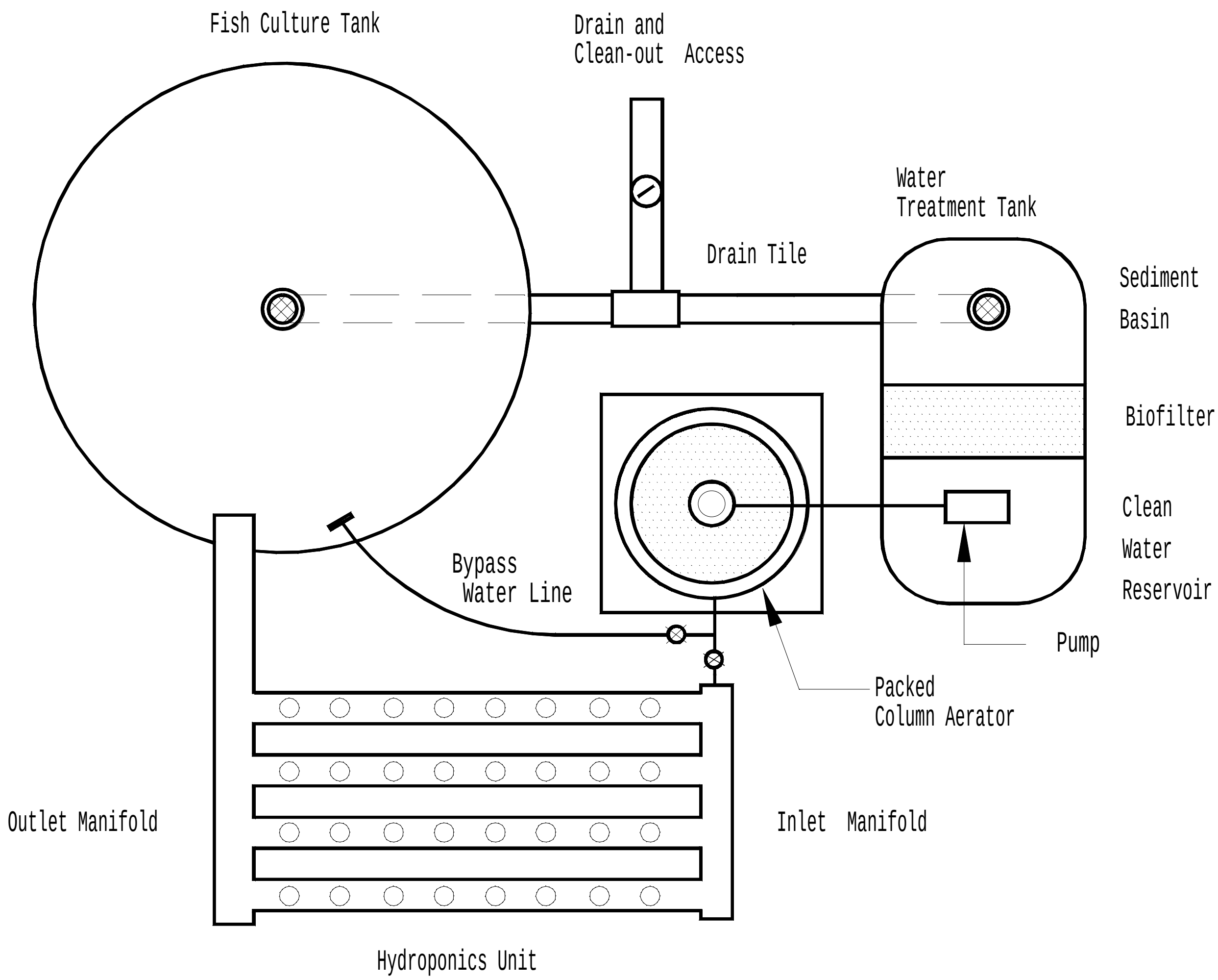

Figure 1. Recirculating Aquaculture-Hydroponics Unit

Fish Culture Tank

The fish culture tank is a 350 gallon (1323 L.) formed rubber livestock tank, six feet (1.8 M.) in diameter. A two inch (5.08 cm) grated shower drain installed in the bottom of the tank allows water to exit the fish culture tank and enter the filtration tank for mechanical and biological treatment prior to continuing through the system.

While the filtration tank will remove larger solid particles that settle to the bottom, fine particles (< 30 microns) tend to remain in the culture tank, suspended in the water. These suspended solids increase oxygen demand and cause gill irritation (Ebling, Losordo, and Delong, 1993). An externally mounted air pump and bubble wand (on the bottom of the tank) may be added to the system to help remove these particles. As the air bubbles rise, suspended particles attach to the bubbles and are brought to the surface, where they are trapped in foam. Periodic manual foam removal eliminates these fine particles from the system. The air-pump and bubble wand also increase the dissolved oxygen level in the culture tank.

Stocking rates will vary by fish species, water quality and aeration efficiency. Most commonly cultured species (channel catfish, rainbow trout, hybrid striped bass, and tilapia) can be stocked at a rate of .25 pounds per gallon (113.5 g/L) (Ebeling,et al., 1995).

Water Treatment Tank

Water treatment is essential in a recirculating aquaculture-hydroponic system. Since little make-up water is introduced into the system, solids and chemicals harmful to the fish must be removed before water is recirculated to the culture tank. Depending on environmental conditions, the treated water may also need to be heated before to leaving the filtration tank.

Sediment Basin. Solids come from two primary sources: uneaten food and fecal material produced by the fish. Solids that settle out of a static water column in one hour or less are considered to be settleable solids (Ebeling, et al., 1995). In round culture tanks such as the main tank in this model, solids settle to the center of the tank and are transferred through the drain to the sediment basin of the water treatment tank. The solids are then removed from the water by a mechanical strainer and remain trapped in the sediment basin. Regular cleaning of the basin, filters and drain tile removes these solids from the system.

Biofilter. High concentrations of total ammonia-nitrogen (TAN), produced as a by-product of protein metabolism, can cause fish mortality (Koeniger, 1997). TAN consists of two fractions: un-ionized ammonia (NH_3) and ionized ammonia (NH_4^+). Ionized ammonia is non-toxic to fish at levels likely to occur in a recirculating system; however, un-ionized ammonia may cause death in concentrations as low as two parts-per-million (2 ppm)(2 mg/L). The purpose of a biological filter is to convert TAN, especially the un-ionized fraction, into nitrate-nitrogen (NO_3). Nitrate-nitrogen is relatively harmless to most aquatic species in concentrations of up to 100 ppm (100 mg/L) and is a water-soluble nitrogen form readily usable by plants (Ebeling, Losordo and DeLong, 1993). Nitrate-nitrogen is removed from the recirculating system through routine system flushing and back washing, naturally occurring denitrification, and plant uptake.

The biofilter, constructed from expanded aluminum, is a 12 inch(30 cm)wide box that fits across the width of the water treatment tank. The box is filled with Styrofoam packing pellets which provide an inert, non-soluble media for the growth of two forms of helpful bacteria. *Nitrosomonas* bacteria use ammonia-nitrogen (in both the ionized and un-ionized form) as an energy source and produce nitrite-nitrogen as a by-product. *Nitrobacter* bacteria use nitrite-nitrogen as an energy source and produce nitrate-nitrogen as a by-product.

Clean Water Basin. After the water has been mechanically filtered and biologically treated, it flows into the clean water basin. Four 300 W thermostatically controlled submersible electric heaters are used to maintain water temperature prior to recirculation. A 1/5 hp (150 W) submersible pump lifts water 4.5 feet (1.4 m) from the clean water basin to the packed column aerator.

<u>Packed Column Aerator</u>

The packed column aerator consists of a 35 gallon (170 L) plastic tank placed inside a 55 gallon (208 L) plastic tank. The small tank is filled with packing media, and has holes in the sides and bottom to allow for the flow of air and water. Water from the clean water basin is pumped to the top of the packed column aerator and is dispersed across the packing media by a low pressure spray nozzle with enlarged orifices.

The packed column aerator operates under non-flood conditions. As water flows through the packing media, the oxygen content of the water increases due to the increased water surface area surface area and the decreased flow rate (Ebeling, Losordo and DeLong, 1993).

Water exits from the bottom of the packed column aerator through an orfice in the large drum. From this point, water flows under gravitational force to either the hydroponic unit or the fish culture tank.

Hydroponic Unit

The hydroponic unit is designed to accomplish two functions. First, the unit must allow water to flow over the plant roots so essential nutrients can be extracted by the plant. Second, the unit must provide the plants with mechanical support. The hydroponic unit can be constructed from a number of materials including PVC pipe, vinyl guttering, and shallow plastic pans. A soil-less medium, such as peat pellets, glass beads or floating Styrofoam(R) strips, can be used to provide mechanical support for the plants.

The fish provide a source of nitrogen for plant growth. However, other micro and macro nutrients may be required, depending on the plants grown. These nutrients may be introduced into the system, but must be monitored to maintain them at levels that are not harmful to the fish. Additionally, light intensity, temperature, humidity, and other environmental factors must be controlled to optimize plant growth.

The authors have successfully grown a variety of vegetables and ornamental flowering plants in the recirculating system. Lettuce, green beans and tomatoes have been grown to maturity without adding nutrients to the solution.

By-Pass Water Line

The amount of water which should flow to the hydroponic unit varies with the size of the unit and the number and size of the plants being grown. Two hand valves, placed in-line ahead of the hydroponic unit and the fish culture tank, allow manual control of water flow to each unit. Under most conditions, a majority of the pump's output is returned to the fish culture tank through the by-pass water line. An aeration nozzle attached to the output of the line helps maintain dissolved oxygen at a safe level (≥ 5ppm, 5 mg/L) in the culture tank.

Classroom Activities Using the System

Many applied science learning activities can be based on the aquaculture-hydroponic unit (see Figure 2 for example activities). The integrated unit provides a model which allows for a systems approach to the study of basic science and math principles and how they apply to plants and animals, and the effects of plants and animals on the environment. Integrated activities which emphasize chemistry can focus around water quality issues. Biological science activities can be conducted on both plants and animals. The unit allows for many activities in applied physics such as hydrology, energy use and pump efficiency, and the design and testing of control and instrumentation systems. Math principles can be applied by recording, analyzing and graphing data on water quality, feed consumption, rate of gain, feed conversion and other variables of interest.

Figure 2.
Example Applied Learning Activities in Science and Math Using the Aquaculture-Hydroponic System.

- Chemistry Activities
  - Water quality studies
    - Monitor dissolved oxygen levels
    - Monitor levels of nitrates
    - Monitor levels of nitrites
  - Determine effects of fish stocking rates on:
    - Dissolved oxygen levels
    - Levels of nitrates
    - Levels of nitrites
  - Determine effects of plants on levels of:
    - Dissolved oxygen levels
    - Levels of nitrates
    - Levels of nitrites
- Biological Science Activities
  - Plant science activities
    - Compare hydroponically grown plants with conventionally grown plants
    - Conduct plant tissue tests
    - Measure plant nutrient uptake
    - Manipulate and monitor micro-nutrient levels
    - Measure plant respiration and transpiration
    - Compare hydroponic growing media
      - Exposed root systems versus active media systems
  - Animal science activities
    - Fish response to stimuli
      - Feeding times
      - Feeding amounts
      - Responses to light and temperature
      - Water quality
    - Conduct animal tissue tests

continued

Fig. 2 continued.

Physical Science Activities

- Hydrology
    - Diffusion of chemicals across various growing media
    - Diffusion of solids through various growing media
- Water flow rates
    - Pump efficiencies
    - Filtration removal of solids
- Heating efficiencies
- Lighting efficiencies
- Control systems
    - Design and testing
    - Mechanical versus electronic
    - Monitoring systems

Summary

The authors constructed an aquaculture-hydroponic unit, suitable for use in laboratory settings, for less than $600. Educators can use the information provided in this article to construct their own unit. The recirculating aquaculture-hydroponic unit is an excellent hands-on system that can be used to learn science and math applications in agriculture. The opportunities for integration of math, science and technology in both creating and utilizing the system are limited only by the imagination of teachers and students.

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Appendix I
Materials list and approximate costs for 350 gal aquaponics unit.

ITEM	***Quantity Unit Cost***	***TOTAL COST***
350 gal molded plastic stock tank	1 @ 189.00	189.00
100 gal molded plastic stock tank	1 @ 69.21	69.21
10 ft plastic guttering sections	2 @ 3.97	7.94
Guttering end caps with seals	8 @ 2.99	23.92
Shop lights	3 @ 8.48	25.44
Florescent bulbs	6 @ .98	5.88
55 gal plastic barrel	1 @ $20	20.00
2" shower drains	2 @ 8.97	17.96
2" PVC Corners	3 @ .85	2.55
2" PVC Ball Valve	1 @ 21.59	21.59
10ft sections of 2" PVC	2 @ 3.49	6.98
2" PVC Tee	1 @ 1.75	1.75
2" rubber 90 deg - w/ PVC	1 @ 7.79	7.79
2" rubber Tee - w/ PVC	1 @ 9.97	9.97
½” PVC to male converters	2 @ .29	.58
2" to 1 ½” PVC reducer	1 @ 1.39	1.39
1 ½” to ½” PVC elbow w/ threading	1 @ .99	.99
GFCI receptacle outlet	1 @ 10.00	10.00
Extension cord (25ft)	1 @ 6.79	6.79
1/5 hp submergible pump	1 @ 69.97	69.97
18 feet - 5/8" clear plastic tubing	18 @ .59	10.62
1" hose clamps	6 @ .65	3.9
6 ft of ½” PVC pipe (in 10ft sections)	1 @ 1.39	1.39
½” Tee with threading	4 @ .59	2.36
½” PVC Tee	1 @ .39	.39
½” to 1/4" nylon hose adaptors	4 @ .59	2.36
½” PVC endcap	1@ .29	.29
½” PVC elbow	3@ .29	.87

½” PVC elbow with threading	2 @ .59	1.18
½” PVC female adaptor	1 @ .35	.35
½” to 5/8" nylon hose adaptor	3 @ .89	2.40
6 ft of 1" PVC (in 10ft sections)	1 @ 2.19	2.19
1" PVC elbow	5 @ .43	2.15
1" PVC Tee	1 @ .49	.49
1" PVC endcap	1 @ .99	.99
1" PVC T w/ 3/4" outlet	2 @ 1.19	2.38
3/4" female PVC adaptor	2 @ .39	.78
3/4" male PVC adaptor	2 @ .45	.9
1" female PVC adaptor	1 @ .49	.49
1" male PVC adaptor	1 @ .59	.59
2"x 4"x 8' lumber	1 @ 3.59	3.59
3/4" 4’x8' sheet foam insulation	1 @ 3.79	3.79
30 gal plastic trash can	1 @ 5.97	5.97
Non-water soluable foam pellets	2 cu.ft. @ local rate	***
Concrete blocks	20 @ 2.00	40.00
TOTAL		**586.33**