Aquaponics—Integration of Hydroponics with Aquaculture

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Aquaponics is a bio-integrated system that links recirculating aquaculture with hydroponic vegetable, flower, and/or herb production. Recent advances by researchers and growers alike have turned aquaponics into a working model of sustainable food production. This publication provides an introduction to aquaponics with brief profiles of working units around the country. An extensive list of resources point the reader to print and Web-based educational materials for further technical assistance.

Contents

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Aquaponic vegetable bed in Australia. Photo by Joel Malcolm, Backyard Aquaponics. *www.backyardaquaponics.com* *(with permission)*

Introduction

Aquaponics, also known as the integration of hydroponics with aquaculture, is gaining increased attention as a bio-integrated food production system.

Aquaponics serves as a model of sustainable food production by following certain principles:

- The waste products of one biological system serve as nutrients for a second biological system.
- The integration of fish and plants results in a polyculture that increases diversity and yields multiple products.
- Water is re-used through biological filtration and recirculation.
- Local food production provides access to healthy foods and enhances the local economy.

In aquaponics, nutrient-rich effluent from fish tanks is used to fertigate hydroponic production beds. This is good for the fish because plant roots and rhizobacteria remove nutrients from the water. These nutrients—generated from fish manure, algae, and decomposing fish feed—are contaminants that would otherwise build up to toxic levels in the fish tanks, but instead serve as liquid fertilizer to hydroponically grown plants. In turn, the hydroponic beds function as a biofilter— stripping off ammonia, nitrates, nitrites, and phosphorus—so the freshly cleansed water can then be recirculated back into the fish tanks. The nitrifying bacteria living in the gravel and in association with the plant roots play a critical role in nutrient cycling; without these microorganisms the whole system would stop functioning.

Greenhouse growers and farmers are taking note of aquaponics for several reasons:

- Hydroponic growers view fish-manured irrigation water as a source of organic fertilizer that enables plants to grow well.
- Fish farmers view hydroponics as a biofiltration method to facilitate intensive recirculating aquaculture.
- Greenhouse growers view aquaponics as a way to introduce organic hydroponic produce into the marketplace, since the only fertility input is fish feed and all of the nutrients pass through a biological process.
- Food-producing greenhouses—yielding two products from one

production unit—are naturally appealing for niche marketing and green labeling.

- Aquaponics can enable the production of fresh vegetables and fish protein in arid regions and on water-limited farms, since it is a water re-use system.
- Aquaponics is a working model of sustainable food production wherein plant and animal agriculture are integrated and recycling of nutrients and water filtration are linked.
- In addition to commercial application, aquaponics has become a popular training aid on integrated bio-systems with vocational agriculture programs and high school biology classes.

Related ATTRA Publications

Evaluating an Aquaculture Enterprise

Agricultural Business Planning Templates and Resources

The technology associated with aquaponics is complex. It requires the ability to simultaneously manage the production and marketing of two different agricultural products. Until the 1980s, most attempts at integrated hydroponics and aquaculture had limited success. However, innovations since the 1980s have transformed aquaponics technology into a viable system of food production. Modern aquaponic systems can be highly successful, but they require intensive management and they have special considerations.

This publication provides an introduction to aquaponics, it profiles successful aquaponic greenhouses, and it provides extensive resources. It does not attempt to describe production methods in comprehensive technical detail, but it does provide a summary of key elements and considerations.

Aquaponics: Key Elements and Considerations

A successful aquaponics enterprise requires special training, skills, and management. The following items point to key elements and considerations to help prospective growers evaluate the integration of hydroponics with aquaculture.

Hydroponics: Hydroponics is the production of plants in a soilless medium whereby all of the nutrients supplied to the crop are dissolved in water. Liquid hydroponic systems employ the nutrient film technique (NFT), floating rafts, and noncirculating water culture. Aggregate hydroponic systems employ inert, organic, and mixed media contained in bag, trough, trench, pipe, or bench setups. Aggregate media used in these systems include perlite, vermiculite, gravel, sand, expanded clay, peat, and sawdust. Normally, hydroponic plants are fertigated (soluble fertilizers injected into irrigation water) on a periodical cycle to maintain moist roots and provide a constant supply of nutrients. These hydroponic nutrients are usually derived from synthetic commercial fertilizers, such as calcium nitrate, that are highly soluble in water. However, hydro-organics—based on soluble organic fertilizers such as fish hydrosylate—is an emerging practice. Hydroponic recipes are based on chemical formulations that deliver precise concentrations of mineral elements. The controlled delivery of nutrients, water, and environmental modifications under greenhouse conditions is a major reason why hydroponics is so successful.

Nutrients in Aquaculture Effluent: Greenhouse growers normally control the delivery of precise quantities of mineral elements to hydroponic plants. However, in aquaponics, nutrients are delivered via aquacultural effluent. Fish effluent contains sufficient levels of ammonia, nitrate, nitrite, phosphorus, potassium, and other secondary and micronutrients to produce hydroponic plants. Naturally, some plant species are better adapted to this system than others. The technical literature on aquaponics provides greater detail on hydroponic nutrient delivery; especially see papers cited in the **Bibliography** by James Rakocy, PhD.

Plants Adapted to Aquaponics: The selection of plant species adapted to hydroponic culture in aquaponic greenhouses is related to stocking density of fish tanks and subsequent nutrient concentration of aquacultural effluent. Lettuce, herbs, and specialty greens (spinach, chives, basil, and watercress) have low to medium nutritional requirements and are well adapted to aquaponic systems. Plants yielding fruit (tomatoes, bell peppers, and cucumbers) have a higher nutritional demand and perform better in a heavily stocked, well established aquaponic system. Greenhouse varieties of tomatoes are better adapted to low light, high humidity conditions in greenhouses than field varieties.

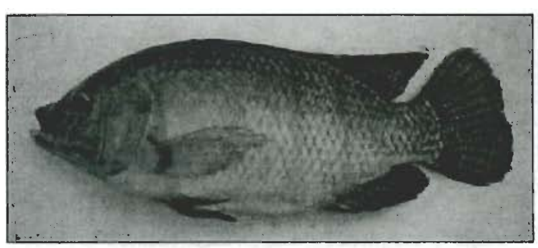
Fish Species: Several warm-water and cold-water fish species are adapted to recirculating aquaculture systems, including tilapia, trout, perch, Arctic char, and bass. However, most commercial aquaponic systems in North America are based on tilapia. Tilapia is a warm-water species that grows well in a recirculating tank culture. Furthermore, tilapia is tolerant of fluctuating water conditions such as pH, temperature, oxygen, and dissolved solids. Tilapia produces a white-fleshed meat suitable to local and wholesale markets. The literature on tilapia contains extensive technical documentation and cultural procedures. Barramundi and Murray cod fish species are raised in recirculating aquaponic systems in Australia.

Water Quality Characteristics: Fish raised in recirculating tank culture require good water quality conditions. Water quality testing kits from aquacultural supply companies are fundamental. Critical water quality parameters include dissolved oxygen, carbon dioxide, ammonia, nitrate, nitrite, pH, chlorine, and other characteristics. The stocking density of fish, growth rate of fish, feeding rate and volume, and related environmental fluctuations can elicit rapid changes in water quality; constant and vigilant water quality monitoring is essential.

Biofiltration and Suspended Solids: Aquaculture effluent contains nutrients, dissolved solids, and waste byproducts. Some aquaponic systems are designed with intermediate filters and cartridges to collect suspended solids in fish effluent, and to facilitate conversion of ammonia and other waste products to forms more available to plants prior to delivery to hydroponic vegetable beds. Other systems deliver fish effluent directly to gravel-cultured hydroponic vegetable beds. The gravel functions as a "fluidized bed bioreactor," removing dissolved solids and providing habitat for nitrifying bacteria involved in nutrient conversions. The design manuals and technical documentation available in the **Resources** section can help growers decide which system is most appropriate.

Component Ratio: Matching the volume of fish tank water to volume of hydroponic media is known as component ratio. Early aquaponics systems were based on a ratio of 1:1, but 1:2 is now common and tank: bed ratios as high as 1:4 are employed. The variation in range depends on type of hydroponic system (gravel vs. raft), fish species, fish density, feeding rate, plant species, etc. For example, the Speraneo system described below is designed for one cubic foot of water to two cubic feet of grow bed media (pea gravel). Further, when shallow bed systems only three inches in depth are employed for the production of specialty greens such as lettuce and basil, the square footage of grow space will increase four times. Depending on the system design, the component ratio can favor greater outputs of either hydroponic produce or fish protein. A "node" is a configuration that links one fish tank to a certain number of hydroponic beds. Thus, one greenhouse may contain a multiple number of fish tanks and associated growing beds, each arranged in a separate node.

Tilapia is a warm-water species that grows well in a recirculating tank culture.



Male tilapia fish. AARM - Aquaculture & Aquatic Resources Management Asian Institute of Technology, Thailand. www.aqua.ait.ac.th/modules/xcgal/

Aquaponic Systems

Profiles of several aquaponic greenhouses are highlighted below as models of commercially viable systems. Most of these operations are featured in magazine articles and conference proceedings. Some operations offer technical assistance through short courses, design manuals, and on-site tours. Please refer to articles in the **Suggested Reading** list, the **Resources** section, and the **Bibliography** for in-depth descriptions and technical details.

The North Carolina State University System

In the 1980's Mark McMurtry (former graduate student) and the late Doug Sanders (professor) at North Carolina State University developed an aqua-vegeculture system based on tilapia fish tanks sunk below the greenhouse floor. Effluent from the fish tanks was trickle-irrigated onto sand-cultured hydroponic vegetable beds located at ground level. The nutrients in the irrigation water fed tomato and cucumber crops, and the sand beds and plant roots functioned as a biofilter. After draining from the beds, the water recirculated back into the fish tanks. The only fertility input to the system was fish feed (32 percent protein).

Water consumption in an integrated aqua-vegeculture system amounts to 1 percent of that required in pond culture to produce equivalent tilapia yields.

Some findings and highlights of McMurtry's research:

- Benefits of integrating aquaculture and vegetable production are:
  1. conservation of water resources and plant nutrients
  2. intensive production of fish protein
  3. reduced operating costs relative to either system in isolation.
- Water consumption in an integrated aqua-vegeculture system amounts to 1 percent of that required in pond culture to produce equivalent tilapia yields.
- Such low-water-use symbiotic systems are applicable to the needs of arid or semi-arid regions where fish and fresh vegetables are in high demand.
- Organic vine-ripened, pesticide-free produce and "fresh-daily" fish can bring premium prices, particularly during winter months in urban areas.
- Biofilters (sand beds with vegetables) that are alternately flooded and drained with nutrient-laden fish tank water are called reciprocating biofilters.
- Reciprocating biofilters provide uniform distribution of nutrient-laden water within the filtration medium during the flood cycle, and improved aeration from atmospheric exchange during each dewatering with benefits to both nitrifying bacteria and plant roots.
- Dissolved and suspended organic materials accumulate rapidly in aquaculture systems and must be removed for efficient fish production.
- Previous integrated fish-vegetable systems removed suspended solids from the water by sedimentation in clarifiers prior to plant application. Removal of the solid wastes resulted in insufficient residual nutrients for good plant growth; acceptable fruit yields had previously only been achieved with substantial supplementation of plant nutrients.
- Aqueous nitrate concentrations in recirculating aquaculture can be adequately regulated when fish and vegetable production are linked via reciprocating biofilters.
- Tomatoes may have also assimilated nitrogen in organic amino acid forms. In 1950 Gosh and Burris (Utilization of nitrogenous compounds by plants. Soil Science. Vol. 70: 187-203) found that tomatoes utilize alanine, glutamic acid, histidine, and leucine as effectively as inorganic nitrogen sources.
- Research to determine the optimum ratio of fish tank to biofilter volume on fish growth rate and water quality found that stocking density of fish and plants can vary depending

on desired goal. The component ratios of the system may be manipulated to favour fish or vegetable production according to local market trends or dietary needs. Fish stocking density and feeding rates are adjusted to optimize water quality as influenced by plant growth rate.

See the **Bibliography on Aquaponics** in the appendix for a of list articles that resulted from the North Carolina research.

Aqua-vegeculture research at NCSU has been discontinued because the technology had evolved to the point where it is ready for grower application. The Department of Horticulture and the Cooperative Extension Service at NCSU provide technical assistance to aquaponic greenhouse growers in North Carolina.

The Speraneo System

In the early 1990s, Tom and Paula Speraneo—owners of S & S Aqua Farm near West Plains, Missouri—modified the North Carolina State method by raising tilapia in a 500-gallon tank, with fish effluent linked to gravel-cultured hydroponic vegetable beds inside an attached solar greenhouse. Later, they expanded to a full-size commercial greenhouse. The Speraneo system was practical, productive, and wildly successful. It became the model for dozens of commercial aquaponic greenhouses and high school biology programs.

Sadly, Tom Speraneo died in February 2004. Tom was a true pioneer in aquaponics, and he was unfailingly generous and helpful to others. Paula Speraneo and her family continue to run the greenhouse and actively participate in aquaponics technology transfer. The following notes describe the Speraneo system and available resources.

The commercial-scale solar greenhouse at S & S Aqua Farm is 50 feet by 80 feet, oriented East-West to create a south-facing slope. It contains six 1,200 gallon fish tanks. Each tank is linked to six one-foot-deep hydroponic beds filled with river gravel. Tom referred to each tank-plus-hydroponic bed setup as a "node." This way, each node can operate independently of one another.

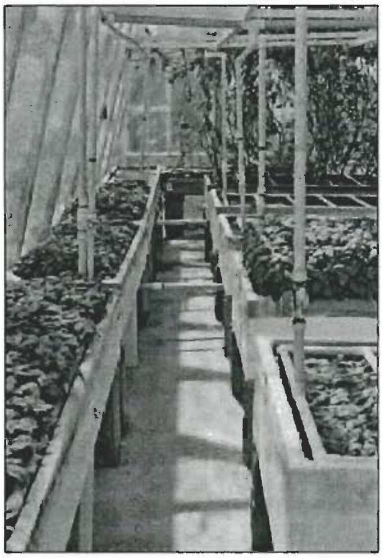
Some aspects of the Speraneo system were modeled after the aquaponics research at North Carolina State University, while others are modified. The Speraneos employ hydroponic vegetable beds as "fluidized bed reactors," but they use pea-grade river gravel instead of sand. Tilapia are raised in fish tanks, but the tanks are more conveniently located above ground and tilapia hybrids adapted to cooler water temperatures are grown. The reciprocating water cycle, PVC piping, and return-flow water pumping methods were designed by Tom and Paula to match their system.

The Speraneo system was practical, productive, and wildly successful.

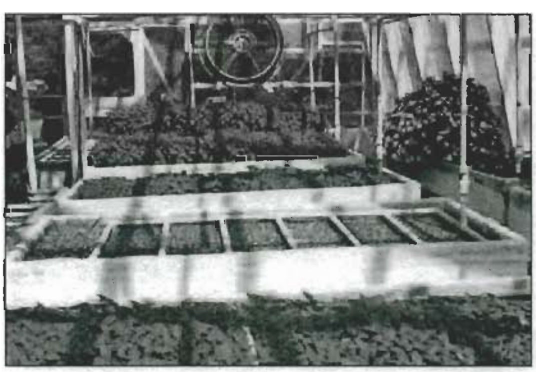
For years, Purina® fish chow at 40 percent protein was the primary fertility input, supplemented with tank-cultured algae. Tilapia in the Speraneo system are raised for 7 to 12 months, then harvested at one to one-and-a-half pounds in size. Later, Tom started adding small amounts of Planters 2® rock dust on top of the gravel as a trace element supplement.

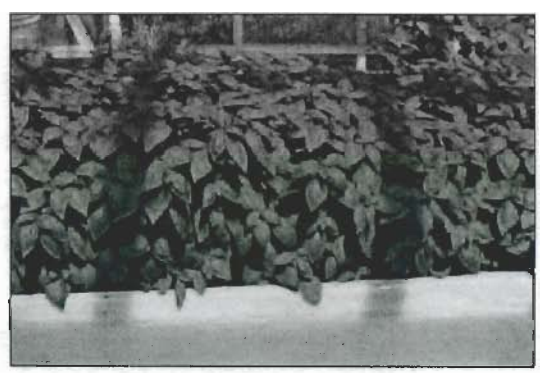
S & S Aqua Farm has grown fresh basil, tomatoes, cucumbers, mixed salad greens, and an assortment of vegetable, herb, and ornamental bedding plants in the aquaponic greenhouse. In the early 1990's, Tom and Paula were raising and selling basil for $12 a pound to gourmet restaurants about four hours away in St. Louis, Missouri. Following passage of the North American Free Trade Agreement (NAFTA), however, Mexican imports of basil resulted in a market crash to $4 per pound, so they dropped the St. Louis market. S & S Aqua Farm now grows a diverse variety of vegetable and herbs, selling locally at a farmers market combined with direct sales out of their greenhouse.

Tom once calculated the farm produces 45 to 70 pounds of produce for every pound of tilapia, an impressive yield. However, Paula explained this figure takes into account the cummulative yields of multiple vegetable crops raised during the 7 to 12 month time period required to raise fish to harvest.



Aquaponic greenhouse at S&S Aqua Farms, West Plains, Missouri. Photos by Steve Diver, NCAT.





The component ratio favors vegetables over fish yields in the Speraneo system.

Interest in the Speraneo system resulted in more than 10,000 visitors to the small farm in Missouri, including school children, farmers, researchers, and government officials. To handle requests for assistance, the Speraneos compiled a resource packet and design manual with technical specifications to establish an S & S Aqua Farm-style aquaponic system. The resource packet includes a 10-minute video and a list of supplies. Response from growers to a practical design manual such as this was tremendous. The Speraneo system is now in use worldwide. The resource packet, which sells for $250, is available through:

S & S Aqua Farm
[Contact: Paula Speraneo]
8386 County Rd. 8820
West Plains, MO 65775
417-256-5124
snsaquasys@townsqr.com
www.townsqr.com/snsaqua/index.html

Especially see:

Maturing Marvel
by Vern Modeland
The Growing Edge, May-June 1998
www.townsqr.com/snsaqua/0905ssaf.pdf

The Genius of Simplicity
by John Wesely Smith
The Growing Edge, Winter 1993-94
www.townsqr.com/snsaqua/0502ssaf.pdf

Bioponics—Revolution in Food Growing: Missouri Aquafarmer Discovers Huge Benefits in Trace Elements
by David Yarrow
Remineralize the Earth, December 1997
www.championtrees.org/topsoil/bioponics.htm

The University of the Virgin Islands System

James Rakocy, PhD, and associates at the University of the Virgin Islands (UVI) developed a commercial-scale aquaponic system that has run continuously for more than five years. Nile and red tilapia are raised in fish rearing tanks, and the aquacultural effluent is linked to floating raft hydroponics. Basil, lettuce, okra, and other crops have been raised successfully, with outstanding quality and yields.

The system components include: Four fish rearing tanks at 7,800 liters each, clarifiers, filter and degassing tanks, air diffusers, sump, base addition tank, pipes and pumps, and six 400-square foot hydroponic troughs totaling 2,400 sq. ft. The pH is monitored daily and maintained at 7.0 to 7.5 by alternately adding calcium hydroxide and potassium hydroxide to the base addition tank, which buffers the aquatic system and supplements calcium and potassium ions at the same time. The only other supplemental nutrient required is iron, which is added in a chelated form once every three weeks.

James Rakocy, PhD, and associates at the University of the Virgin Islands (UVI) developed a commercial-scale aquaponic system that has run continuously for more than five years.

Tilapia are stocked at a rate of 77 fish per cubic meter for Nile tilapia, or 154 fish per cubic meter for red tilapia and cultured for 24 weeks. The production schedule is staggered so that one tank is harvested every six weeks. After harvest, the fish tank is immediately restocked. The fish are fed three times daily with a complete, floating fish pellet at 32 percent protein. Projected annual fish production is 4.16 metric tons for Nile tilapia and 4.78 metric tons for red tilapia.

In one notable experiment the UVI researchers compared the yields of a leafy herb (basil) and a fruiting vegetable (okra) grown in aquaponic vs field production systems. Basil and okra were raised in raft hydroponics. Yields of aquaponic basil were three times greater than field-grown, while yields of aquaponic okra were 18 times greater than field-grown. Based on a market price in the U.S. Virgin Islands of $22 per kg for fresh basil with stems, researchers calculated gross income potential. The aquaponic method would result in $515 per cubic meter per year or $110,210 per system per year. This compares to field-produced basil at $172 per cubic meter per year or $36,808 per year for the same production area. When fish sales are included, the aquaponic system yields $134,245. (1)

Like McMurtry, researcher Rakocy sees integrated water reuse systems as a viable solution to sustainable food production in developing countries and arid regions—such as the Caribbean Islands—where fresh water is scarce.

To provide in-depth technical support, the UVI research team offers a week-long short course on aquaponics each year at the UVI agricultural experiment station. The UVI short course is the premier educational training program available to farmers in the world. In addition to aquaponics, UVI specializes in greenwater tank culture, a recirculating aquaculture system.

Like McMurtry, researcher Rakocy sees integrated water reuse systems as a viable solution to sustainable food production in developing countries and arid regions—such as the Caribbean Islands—where fresh water is scarce.

Rakocy has published extensive research reports and several Extension Service bulletins on recirculating aquaculture and aquaponics. See the **Bibliography** in the appendix for citations to articles and papers by Rackocy.

Contact:

James Rakocy, PhD
University of the Virgin Islands
Agriculture Experiment Station
RR 1, Box 10,000
Kingshill, St. Croix
U.S. Virgin Islands 00850-9781
340-692-4020
jrakocy@uvi.edu
http://rps.uvi.edu/AES/Aquaculture/aqua.html
http://rps.uvi.edu/AES/Aquaculture/aquaponics.html

Especially see:

Update on Tilapia and Vegetable Production in the UVI Aquaponic System
James E. Rakocy, Donald S. Bailey, R. Charlie Shultz and Eric S. Thoman page 676-690. *In*: New Dimensions on Farmed Tilapia: Proceedings of the Sixth International Symposium on Tilapia in Aquaculture, Held September 12-16, 2004 in Manila, Philippines.
Proceedings paper: 15 pages
http://ag.arizona.edu/azaqua/ista/ista6/ista6web/pdf/676.pdf
PowerPoint presentation; 49 pages
http://ag.arizona.edu/azaqua/ista/ista6/ista6web/presentation/p676.pdf

Aquaponics: Integrated Technology for Fish and Vegetable Production in Recirculating Systems
James Rakocy, University of the Virgin Islands
USDA Ministerial Conference and Expo on Agricultural Science and Technology
PowerPoint presentation; 69 slides
http://ffas.usda.gov/icd/stconf/session2/session%202d/02-rakocy_j-2D%202nd_files/frame.htm

The Freshwater Institute System

The Freshwater Institute in Shepherdstown, West Virginia—a program of The Conservation Fund, an environmental non-profit organization—specializes in aquaculture research and education. Fresh spring water is an abundant resource in the Appalachian region. However, protection of spring water quality as it relates to aquaculture effluent is viewed as a vital component of this technology.

For years, the institute has specialized in cold-water recirculating aquaculture systems raising trout and arctic char. The institute helps Appalachian farmers set up two types of aquaculture systems: (a) an indoor, high-tech recirculating tank method and (b) an outdoor, low-tech recirculating tank method. Treatment of aquaculture effluent prior to its return to the natural stream flow led to collaborative research with USDA-ARS scientists in Kearneysville, West Virginia, on integrated hydroponic-fish culture systems. Trials at the institute's greenhouses showed that nitrogen, phosphorus, and other nutrients in aquaculture effluent can be effectively removed by plants grown in NFT hydroponics or constructed wetland systems.

In the mid-1990s, the institute implemented an aquaponic demonstration program based on a Sperraneo-style gravel-cultured system. Tilapia is raised as a warm-water fish species. Hydroponic crops include basil, lettuce, and wetland plants.

To provide technical assistance to farmers and high school biology teachers, the institute published a series of publications on recirculating aquaculture and aquaponics. *The Freshwater Institute Natural Gas Powered Aquaponic System—Design Manual* is a 37-page manual published by the institute in 1997. Included are diagrams and photos, details on greenhouse layout and aquaponic production, parts list with suppliers and cost, estimated operating expense, and further informational resources.

Please note the institute no longer provides direct technical assistance to farmers on aquaponics. Instead, it has made the aquaponics design manual and related publications on recirculating aquaculture and aquaponics available as free Web downloads.

The Freshwater Institute
Shepherdstown, WV
www.freshwaterinstitute.org

Selected Web Publications from The Freshwater Institute

- Suggested Management Guidelines for An Integrated Recycle Aquaculture – Hydroponic System
- The Freshwater Institute Natural Gas Powered Aquaponic System - Design Manual
- 880 Gallon Recycle Aquaculture System Installation Guide
- Linking Hydroponics to a 880 Gallon Recycle Fish Rearing System
- Operators Manual for 880 - Recycle System

The Cabbage Hill Farm System

Cabbage Hill Farm is a non-profit organization located about 30 miles north of New York City. The foundation is dedicated to the preservation of rare breeds of farm animals, sustainable agriculture and local food systems, and aquaponic greenhouse production. Cabbage Hill Farm designed and continues to operate a simple recirculating aquaponic system. Cabbage Hill Farm promotes education on aquaponics and hosts greenhouse interns. Tours are available.

Tilapia fish and leaf lettuce are the main products of the Cabbage Hill Farm system, though basil and watercress are also grown in smaller quantities. In addition to hydroponics, water passes through a constructed reed bed outside the greenhouse for additional nutrient removal.

Aquaponics—Preserving the Future is a video film documenting the research and demonstration of aquaponics at Cabbage Hill Farms. The cost is $18.

Cabbage Hill Farm
205 Crow Hill Road
Mount Kisco, NY 10549
914-241-2658
914-241-8264 FAX
www.cabbagehillfarm.org

Cabbage Hill Farm promotes education on aquaponics and hosts greenhouse interns.

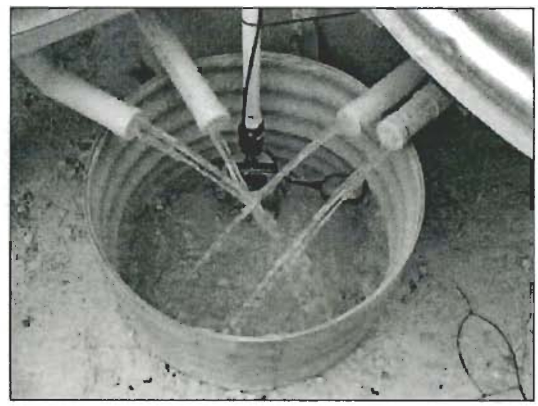
The New Alchemy Institute

The New Alchemy Institute in East Falmouth, Massachusetts, conducted research on integrated aquaculture systems during the 1970s and 1980s. Although the institute closed in 1991, New Alchemy publications on greenhouse production and aquaponics provide historical insight to the emerging bioshelter (ecosystem greenhouses) concept and are still a valuable resource for technical information. The Green Center, formed by a group of former New Alchemists, is again making these publications available for sale. The Web site has a section featuring for-sale articles on aquaculture and bioshelters (integrated systems). A selection of past articles is available online.

Contact:

The Green Center
237 Hatchville Rd.
East Falmouth, MA 02536
www.vsb.cape.com/~nature/greencenter/

Backyard Aquaponics in Western Australia. Photos by Joel Malcolm, Backyard Aquaponics. (with permission) *www.backyard aquaponics.com*



Especially see:

An Integrated Fish Culture Hydroponic Vegetable Production System
by Ronald D. Zweig
Aquaculture Magazine, May-June 1986.
www.vsb.cape.com/~nature/greencenter/pdf/zweig.pdf

Summary of Fish Culture Techniques in Solar Aquatic Ponds
by John Wolfe and Ron Zweig
Journal of The New Alchemists, 1977
www.vsb.cape.com/~nature/greencenter/pdf/j6ponds.pdf

Miscellaneous Systems

Instead of locating the fish and vegetable components in separate containers inside a greenhouse, fish production can be located in outdoor tanks or adjacent buildings. The effluent simply needs to be delivered to hydroponic vegetable beds.

In warm climates, hydroponic vegetable beds may be located outside. As an example, the Center for Regenerative Studies at California State Polytechnic University-Pomona implemented an outdoor integrated bio-system that links: (a) a pond containing treated sewage wastewater stocked with tilapia and carp; (b) water hyacinth—an aquatic plant very efficient at sucking up nutrients—covering 50 percent of the water surface area; the plant biomass generated by water hyacinth is used as feedstock for compost heaps; (c) nearby vegetable gardens irrigated with nutrient-laden pond water.

In addition to locating the fish and vegetable components in separate containers, fish and plants can be placed in the same container to function as a polyculture. For example, plants sit on top of floating polystyrene panels with their roots hanging down into the water that fish swim around in. Models include the Rackocy system, solar-algae ponds (see literature by Zweig and Kleinholz), and the solar-aquatic ponds, or Living Machines, made popular by John Todd at Ocean Arks International.

In Australia, barramundi (*Lates calcarifer*) and Murray cod (*Maccullochella peelii peelii*) fish species have been adapted to recirculating aquaculture and aquaponics systems. The stocking densities for these fish species is higher than tilapia, which in turn results in greater hydroponic surface under production. Several references are provided on these fish species and aquaponic systems in the **Resources** and **Bibliography** sections.

Organic Aquaculture

Organic production of crops and livestock in the United States is regulated by the Department of Agriculture's National Organic Program, or NOP. The NOP is an organic certification and marketing program that ensures foods and food products labeled as "organic" meet universal standards and guidelines for organic production. Production inputs used in organic production—such as feed and fertilizers—must be of natural origin and free of synthetic materials. A farm plan, documentation of inputs and production methods, and farm inspection are required to obtain "certified organic" status. This process allows farm products to be labeled and sold as organic.

Organic production of crops and livestock in the United States is regulated by the Department of Agriculture's National Organic Program, or NOP.

Organic trout, tilapia, salmon and other fish species are raised in Europe, Australia, and Israel using production standards developed by international organic certification agencies. However, organic aquaculture was not clearly defined in the NOP and the lack of organic aquaculture guidelines has hampered the growth of a domestic organic aquaculture industry in the United States.

The ATTRA publication *Evaluating an Aquaculture Enterprise* contains a section on organic aquaculture. It states that accredited organic certifying agencies can certify organic aquaculture operations, but the products are not allowed to carry the USDA organic label.

In fact, Quality Certification Services in Florida has certified about a dozen organic aquaculture operations in the U.S. and abroad under a private label. AquaRanch, an aquaponic greenhouse in Illinois, set a precedent for the aquaponics industry by obtaining organic certification for its hydroponic produce through Indiana Certified Organic. Meanwhile, AquaRanch markets its greenhouse-raised tilapia as "naturally grown."

To address the issue of organic aquaculture, the National Organic Standards Board (NOSB) established an Aquatic Animals Task Force in June 2000. In 2003, a second group—The National Organic Aquaculture Working Group (NOAWG), comprised of 80 aquaculture professionals and related stakeholders—formed to provide further guidance and clarification to the NOSB. The 81-page white paper published by NOAWG in May 2005 provides historical notes and documents on this topic as well as the currently proposed recommendations to NOSB, accessible through the Aqua KE Government Documents collection at *http://govdocs.aquake.org/cgi/content/abstract/2005/801/8010170.*

Due to the highly technical nature of aquaponics and the expense associated with greenhouse production, prospective growers are advised to thoroughly investigate production methods and market potential.

To provide guidance to the large volume of documents, reports, and organic production standards surrounding the issue of organic aquaculture, the National Agricultural Library published an 80-page bibliography, Organic Aquaculture, through the Alternative Farming Systems Information Center.

Organic Aquaculture
AFSIC Notes #5
Stephanie Boehmer, Mary Gold, Stephanie Hauser, Bill Thomas, and Ann Young
Alternative Farming Systems Information Center, National Agricultural Library, USDA
www.nal.usda.gov/afsic/AFSIC_pubs/afnotes5.htm

Evaluating an Aquaponic Enterprise

For general information and supplies associated with greenhouse vegetable production, see the ATTRA resource list *Greenhouse Vegetable Production and Greenhouse & Hydroponic Vegetable Production Resources on the Internet.* Complementary ATTRA publications include *Organic Greenhouse Vegetable Production* and *Integrated Pest Management for Greenhouse Crops.*

Building and equipping a commercial-sized aquaponic greenhouse can cost $10,000 to $30,000, depending on the system design and choice of components. Due to the highly technical nature of aquaponics and the expense associated with greenhouse production, prospective growers are advised to thoroughly investigate production methods and market potential. A sequence of considerations and learning opportunities geared to evaluating an aquaponic greenhouse enterprise are listed below.

1) Aquaponic greenhouses yield two food products. To evaluate greenhouse profitability, obtain typical yields and market prices for hydroponic vegetables and fish, and investigate local and regional markets and related point of sales. Retail sales directly out of your greenhouse or roadside stand might be an ideal situation, but this will depend on your location.

2) Aquaponics is one method of hydroponics, and hydroponics is one method of greenhouse production. Consider lower-cost and simpler alternatives. Bag culture of greenhouse vegetables—raising plants in polyethylene grow bags filled with compost-based potting mixes—is a simple and productive way to get started in greenhouse vegetable production. You may quickly find that your biggest challenge is weekly marketing of fresh produce rather than successful production of vegetables. This includes labor to harvest vegetables, grading and packing with brand name labels, post-harvest handling methods to maintain superior quality, and quick delivery of perishable produce to established markets.

3) Read technical and popular literature on recirculating aquaculture and aquaponics to become familiar with production methods, yields, and market prices for fresh fish and hydroponic vegetables. The **Web Resources** listed below provide quick access to reading material, diagrams and images, and

related details. The **Bibliography** in the **Appendix** provides access to in-depth research and technical data.

4) Visit an aquaponic greenhouse to gain first-hand observations. Take lots of pictures to document the system components and how they relate to one another. Keep in mind that aquaponic growers are busy people with a considerable investment in time and resources to establish their businesses.

5) Attend a short course. There are three prominent aquaponic short courses in North America, offered by University of the Virgin Islands, (2) Aquaculture International (3) in North Carolina, and Grow Power (4) in Wisconsin. Cornell University co-hosts a recirculating aquaculture short course in association with The Freshwater Institute. (5)

6) Obtain one or two aquaponic training manuals to acquire detailed technical specifications. The Cabbage Hill video ($18) can provide a quick overview of an aquaponic system. The *Desktop Aquaponics Booklet* ($15) and the *Introduction to Aquaponics DVD* ($50) from Nelson/Pade Multimedia are another good starting point. When you are ready to explore a commercial system, the design manuals from S&S Aqua Farm ($250) in Missouri and Joel Malcolm's *Backyard Aquaponics* ($95) in Western Australia contain in-depth technical specifications, illustrations, and parts lists (6–7). The **Web Resources** section lists additional training manuals and technical documentation.

7) Hire an agricultural consultant to acquire expert advice and consultation, and to shorten the time and risk involved getting started. A few consultants with expertise in aquaponics are listed in the **Agriculture Consultants** section below.

8) Participate on the Aquaponics E-mail Discussion Group. E-mail discussion lists have become the modern town square. This is where practitioners, scientists, specialists, and business people all share resources, supplies, and production methods. The e-mail list is hosted by Paula Speraneo with S&S Aqua Farms. The archives are publicly accessible, and serve as a treasure trove of technical information and farmer-to-farmer exchange. See below.

9) Lastly, avoid the "inventor's urge" to re-invent the wheel. Successful aquaponic greenhouse operators have already figured out the system components and methods of production, based on years of research and experience. Pick one of the existing models and duplicate it insofar as possible. The old saying, "Get the engine running first, then adjust the carburetor," can be aptly applied to aquaponic start-up greenhouses.

References

1. Rakocy, James E., Donald S. Bailey, R. Charlie Shultz and Eric S. Thoman. 2004. Update on tilapia and vegetable production in the UVI aquaponic system. p. 676-690. *In*: New Dimensions on Farmed Tilapia: Proceedings of the Sixth International Symposium on Tilapia in Aquaculture, Held September 12-16, 2004 in Manila, Philippines.
2. University of the Virgin Islands—Short Course on Aquaponics
   http://rps.uvi.edu/AES/Aquaculture/UVIShortCourse.html
3. Aquaculture International—Short Course on Aquaponics
   www.aquacultureinternational.org
4. Grow Power—Short Course on Aquaponics
   www.growingpower.org
5. Cornell University—Short Course on Recirculating Aquaculture
   www.aben.cornell.edu/extension/aquaculture/shortcourse.htm
6. S&S Aqua Farm—Design Manual
   www.townsqr.com/snsaqua/index.html
7. Joel Malcolm—Backyard Aquaponics Design Manual
   Western Australia
   jmalcolm@iinet.net.au
   www.backyardaquaponics.com

Resources

E-mail Discussion Lists for Aquaponics - Hydroponics - Aquaculture

Aquaponic E-Mail List

Paula Speraneo of S & S Aqua Farm in Missouri hosts the Aquaponics E-Mail List on the Internet. The Aquaponics List is a prominent source of technology transfer and resource sharing on all aspects of aquaponics: hydroponics, aquaculture, fish species, supplies, practical solutions, and resources. The e-mail archives are a key source of information.

To subscribe, send an email request to: *aquaponics-subscribe@townsqr.com*

To view Web e-mail archives, go to:

Aquaponics List—2002 Onwards
http://mid-south.net/pipermail/aquaponics_mid-south.net/

Aquaponics List—Before 2002
http://www.i55mall.com/aquaponics/

Hydroponics and Aquaculture E-Mail List

A number of e-mail lists on hydroponics and aquaculture are scattered among the Internet hosting sites like YahooGroups.com, MSN.com, and Topica.com.

Trade Magazines

Aquaponics Journal
Nelson/Pade Multimedia
P.O. Box 1848
Mariposa, CA 95338
209-742-6869
info@aquaponics.com
www.aquaponicsjournal.com

Aquaponics Journal *is the quarterly journal from Nelson/Pade Multimedia. It has become a prominent source for articles, reports, news, and supplies for the aquaponics industry. Back issues are a valueable resource, available in print or as e-files. Print Subscription, $39/year; E-Subscription, $29/year.*

The Growing Edge Magazine
New Moon Publishing
P.O. Box 1027
Corvallis, OR 97339-1027
800-888-6785
541-757-8477
541-757-0028 Fax
www.growingedge.com

The Growing Edge *is a bi-monthly trade magazine on high-tech gardening systems like hydroponics, bioponics, aquaponics, and ecologically based pest management. Past articles are an important source of technical information on aquaponics, bioponics, and organic hydroponics. Subscription: $27/year; back issues $5 each.*

Practical Hydroponics & Greenhouses
P.O. Box 225
Narrabeen, NSW 2101 Australia
Phone: +61 (02) 9905 9933
Fax: +61 (02) 9905 9030
info@hydroponics.com.au
www.hydroponics.com.au

Practical Hydroponics & Greenhouses *is a bi-monthly magazine dedicated to soilless culture and greenhouse production. Articles profile soilless culture and greenhouse enterprises from around the world. It also reports on new products, research and development, and industry news. Back issues are a valuable resource. The award-winning magazine is now online as an exact digital copy of the print edition, using DjVu technology. Subscription: $60 Australian/year.*

Aquaculture Magazine
P.O. Box 1409
Arden, NC 28704
828-687-0011
828-681-0601 FAX
877-687-0011 Toll-Free
comments@aquaculturemag.com
www.aquaculturemag.com

Aquaculture Magazine *is the trade magazine for aquaculture and fish culture. It publishes a regular issue every two months, an Annual Products Guide each summer and The Buyers Guide and Industry Directory each December. Subscription: $19/year; back issues $5.*

Grower Talks
www.growertalks.com

Greenhouse Management & Production
www.greenbeam.com

Greenhouse Grower
www.greenhousegrower.com

Greenhouse Product News
www.gpnmag.com

World Aquaculture
www.was.org/main/summary.asp?page=magazine

Aquafeed.com
http://aquafeed.com

Austasia Aquaculture
www.austasiaaquaculture.com.au

Aquaponic Books and Videos

Nelson/Pade Multimedia, publisher of Aquaponics Journal, offers booklets, DVDs, videos, and educational curricula on aquaponics, hydroponics, and aquaculture. See their Web page for details. Contact:

Nelson/Pade Multimedia
P.O. Box 1848
Mariposa, CA 95338
209-742-6869
info@aquaponics.com
www.aquaponics.com

Agricultural Consultants for Integrated Hydroponics and Aquaculture

AquaRanch Industries, LLC
[Contact: Myles Harston]
404 D. East Lincoln St.
P.O. Box 658
Flanagan, IL 61740
309-208-5230
815-796-2978
309-923-7479 FAX
info@aquaranch.com
www.aquaranch.com

Fisheries Technology Associates, Inc.
[Contact: Bill Manci]
506 Wabash Street
Fort Collins, CO 80522-3245
970-225-0150
info@ftai.com
www.ftai.com

Future Aqua Farms Limited
[Contact: Carla MacQuarrie]
RR2, Site 1a, Box 26
Head of Chezzetcook, NS
Canada B0J 1N0
902-827-3682
Carla1@ns.sympatico.ca
www.futureaquafarms.com

Global Aquatics USA, Inc.
505 Aldino Stepney Rd.
Aberdeen, MD 21001 USA
443-243-8840
410-734-7473 FAX
aquatic@iximd.com
www.growfish.com

Gordon Creaser
5431 S. Bracken Court
Winter Park, FL 32792
407-671-5075
407-671-5628 FAX
GordonCreaser06@aol.com
www.gordoncreaser.com

Mark R. McMurtry
PMB 267
1627 W. Main St.
Bozeman, MT 59715-4011
406-580-0382
mcmurtry@3riversdbs.net

Nelson/Pade Multimedia
[Contact: John Pade and Rebecca Nelson]
P.O. Box 1848
Mariposa, CA 95338
209-742-6869
info@aquaponics.com
www.aquaponics.com

S&S Aqua Farms
[Contact: Paula Speraneo]
8386 County Rd. 8820
West Plains, MO 65775
417-256-5124
snsaquasys@townsqr.com
www.townsqr.com/snsaqua/index.html

Aquaculture Associations

Aquacultural Engineering Society
www.aesweb.org

American Tilapia Association
http://ag.arizona.edu/azaqua/ata.html

The Alternative Aquaculture Association
www.altaqua.com

Directory of Aquaculture Associations
Aquaculture Network Information Center (AquaNIC)
http://aquanic.org/publicat/govagen/nal/associat.htm

Aquaculture Directories and Resource Collections

National Agricultural Library—Alternative Farming Systems Information Center

> *The Alternative Farming Systems Information Center (AFSIC) at the National Agricultural Library, a program of USDA-ARS, provides extensive*

aquaculture resource listings. Organic Aquaculture *(AFSIC Notes No. 5), published in January 2005, is an important new publication from AFSIC that addresses the potential of organic aquacultural products; it also contains a section on recirculating aquaculture.*

Aquaculture Resources
www.nal.usda.gov/afsic/afsaqua.htm

- Organic Aquaculture
- Aquaculture-Related Internet Sites and Documents
- Directory of Aquaculture Related Associations and Trade Organizations
- Directory of State Aquaculture Coordinators and Contacts
- Automated Searches on General Aquaculture Topics

AFSIC, NAL, USDA-ARS
10301 Baltimore Ave., Room 132
Beltsville, MD 20705-2351
301-504-6559
301-504-6409 Fax
afsic@nal.usda.gov
www.nal.usda.gov/afsic/index.html

The Aquaculture Center—Educational Resources
Virginia Tech University
www.fw.vt.edu/fisheries/Aquaculture_Center/educational_resources.htm

Virginia Tech offers aquaculture eduational curricula, fact sheets, and PowerPoint presentations, including a section on recirculating aquaculture. Proceedings of the Recirculating Aquaculture Conference held in Roanoke, VA, in 1996, 1998, 2000, 2002, and 2004 are available in CD-ROM, and hard copies (except for 1996); inquire with Ms. Terry Rakestraw (aqua@vt.edu) in the Food Science & Technology Department.

Aquaculture Network Information Center (AquaNIC)
http://aquanic.org/index.htm

AquaNIC is the gateway to the world's electronic resources for aquaculture information. Especially see the extensive resource listing on recirculating aquaculture systems, and the complete listing of publications from the Regional Aquaculture Centers.

Recirculating Aquaculture Systems—Index

Aquaculture Network Information Center (AquaNIC)
http://aquanic.org/beginer/systems/recycle.htm

Regional Aquaculture Center Publications—Index
Aquaculture Network Information Center (AquaNIC)
http://aquanic.org/publicat/usda_rac/fact.htm

- Center for Tropical and Subtropical Aquaculture
- North Central Regional Aquaculture Center
- Northeastern Regional Aquaculture Center
- Southern Regional Aquaculture Center
- Western Regional Aquaculture Center

Aqua KE
http://govdocs.aquake.org

Aqua Ke, or Aquaculture Knowledge Environment, is a database and documents library featuring full-text access to aquaculture articles and government reports. The library is organized by themes for browsing of aquacultue topics. The database provides keyword, author, and title search capacity for hundreds of scientific journals via a portal to Stanford University's HighWire Press database.

Environmentally Friendly Aquaculture Digital Library
National Sea Grant Library
http://nsgd.gso.uri.edu/aquadig.html

The National Sea Grant Library (NSGL) contains a complete collection of Sea Grant funded work. The NSGL maintains a bibliographical database containing over 36,000 records that can be searched by author-keyword or browsed by topic. Selected items include proceedings from recirculating aquaculture conferences and related documents. The Environmentally Friendly Aquaculture Digital Library is a topic-oriented portal to NSGL, organized by subject category.

Aquaponic Resources on the Web

Selected Publications from Southern Regional Aquaculture Center (SRAC)

Recirculating Aquaculture Tank Production Systems: Integrating Fish and Plant Culture
SRAC Publication No. 454
http://srac.tamu.edu/tmppdfs/6807933-454fs.pdf

Recirculating Aquaculture Tank Production Systems: An Overview of Critical Considerations
SRAC Publication No. 451
http://srac.tamu.edu/tmppdfs/6807933-451fs.pdf

Recirculating Aquaculture Tank Production Systems: Management of Recirculating Systems
SRAC Publication No. 452
http://srac.tamu.edu/tmppdfs/6807933-452fs.pdf

Recirculating Aquaculture Tank Production Systems: Component Options
SRAC Publication No. 453
http://srac.tamu.edu/tmppdfs/6807933-453fs.pdf

Tank Culture of Tilapia
SRAC Publication No. 282
http://srac.tamu.edu/tmppdfs/6807933-282fs.pdf

Selected Aquaponic Training Materials and Design Manuals

S&S Aqua Farm
www.townsqr.com/snsaqua/index.html

Design manual with specifications

Backyard Aquaponics
www.backyardaquaponics.com

Design manual with specifications

A Prototype Recirculating Aquaculture-Hydroponic System
By Donald Johnson and George Wardlow
University of Arkansas, Department of Agricultural and Extension Education
AgriScience Project
www.uark.edu/depts/aeedhp/agscience/aquart2.pdf

A 10-page reprint article, originally published in Journal of Agricultural Mechanization (1997). It describes a low cost (less than $600) recirculating aquaculture-hydroponic system suitable for use in laboratory settings, including a materials list with approximate cost of materials to set up a 350-gallon aquaponic unit.

The Freshwater Institute Publications Index
Shepherdstown, West Virginia
www.conservationfund.org/conservation/freshwater/index.html

- Suggested Management Guidelines for An Integrated Recycle Aquaculture – Hydroponic System
- The Freshwater Institute Natural Gas Powered Aquaponic System - Design Manual
- 880 Gallon Recycle Aquaculture System Installation Guide
- Linking Hydroponics to a 880 Gallon Recycle Fish Rearing System
- Operators Manual for 880 - Recycle System

Aquaculture on Cat Beach
HTML
www.itv.se/rainbow/english/index.html
DOC
www.itv.se/rainbow/bilder/education_short.doc

A 10-page booklet with directions on establishing a small aquaponic system, including a parts list. The HTML version contains additional photos that illustrate system components and greenhouse production.

OneSeedling.com
www.oneseedling.com

Paul and Bonnie Range, homesteaders in Texas, offer two aquaponic manuals: Small Unit Aquaponics Manual *and* Simplified Aquaponics Manual *for $20 each.*

Barrel-Ponic (aka Aquaponics in a Barrel)
By Travis W. Hughey
www.aces.edu/dept/fisheries/education/documents/barrel-ponics.pdf

General Aquaponic Resources on the Web

The Essence of Aquaponics—Index to Aquaponics Mail Group Topics
www.itv.se/rainbow/mailgroup/index.html

The Essence of Aquaponics Web site of Pekka Nygard and Stefan Goës in Sweden provides an index to key topics (aquaponics, fish, fish feed, plants, plant nutrition, water, biofilters, greenhouses, maintenance, economics, links, literature) posted on the Aquaponics Mail Group (see e-mail resources above).

Aquaponics Library
http://aquaponicslibrary.20megsfree.com/Index.htm

Enhancing Student Interests in the Agricultural Sciences through Aquaponics
by G.W. Wardlow and D.M. Johnson
University of Arkansas, Department of Agricultural and Extension Education
www.uark.edu/depts/aeedhp/agscience/aquart.pdf

Aquaponics - The Theory Behind Integration
by Wilson Lennard
Gippsland Aquaculture Industry Network
www.growfish.com.au/content.asp?ContentId=1060

ADM - Turning Waste into Growth
Practical Hydroponics & Greenhouses, May-June 2000
www.hydroponics.com.au/back_issues/issue52.html

Tailormade Aquaponics
Practical Hydroponics & Greenhouses, November-December 1998
www.hydroponics.com.au/back_issues/issue43.html

Aquaponics Simplified
Practical Hydroponics & Greenhouses, July-August 2005
www.hydroponics.com.au/back_issues/issue83.html

Young's Greenhouses, Texas
Practical Hydroponics & Greenhouses, January-February 2000
www.hydroponics.com.au/back_issues/issue50.html

Aquaponics Proves Profitable in Australia
Aquaponics Journal, First Quarter, 2002.
www.aquaponicsjournal.com/articleaustralia.htm

Developing an Aquaponic System
Aquaponics Journal, July-August 1999
www.bagelhole.org/?page=250

Vertical Aquaponics
by Tom Osher
www.bagelhole.org/?page=288

Integrated Systems of Agriculture and Aquaculture
Aquaculture in the Classroom, University of Arizona
http://ag.arizona.edu/azaqua/extension/Classroom/Aquaponics.htm

Aquaculture on the Web

Greenhouse Tilapia Production in Louisiana
Louisiana State University
www.lsuagcenter.com/en/crops_livestock/aquaculture/tilapia/Greenhouse+Tilapia+Production+in+Louisiana.htm

Recirculating Aquaculture Systems -- Teacher's Resource Web Site
Auburn University
www.aces.edu/dept/fisheries/education/recirculatingaquaculture.php

The Urban Aquaculture Manual
by Jonathan Woods
www.webofcreation.org/BuildingGrounds/aqua/TOC.html

Regional Aquaculture Centers sponsored by the Extension Service

Northeastern Regional Aquaculture Center (NRAC)
www.nrac.umd.edu

North Central Regional Aquaculture Center (NCRAC)
www.ncrac.org

Southern Regional Aquaculture Center (SRAC)
www.msstate.edu/dept/srac/

Western Regional Aquaculture Center (WRAC)
www.fish.washington.edu/wrac/

Center for Tropical and Subtropical Aquaculture
www.ctsa.org

Aquaculture Network Information Center
www.aquanic.org

Fisheries Publications at Texas A&M
http://agpublications.tamu.edu/pubs/efish/

Southern Regional Aquaculture Center Publications at Texas A&M
http://srac.tamu.edu

Scientific Journals on Aquaculture
Aquaculture (Elsevier journal)
www.sciencedirect.com/science/journal/00448486

Aquacultural Engineering (Elsevier journal)
www.sciencedirect.com/science/journal/01448609

Aquaculture International (Springer journal)
www.springerlink.com/link.asp?id=100128

Aquaculture Research (Blackwell journal)
www.blackwell-synergy.com/loi/are

Integrated Bio-Systems on the Web

Internet Conference on Integrated Bio-Systems in Zero Emissions Applications
www.ias.unu.edu/proceedings/icibs/

> **Demonstrating Ecological Engineering for Wastewater Treatment in a Nordic Climate using Aquaculture Principles in a Greenhouse Mesocosm**
> by Bjorn Guterstam and Lasse Forsberg
> Internet Conference on Integrated Bio-Systems in Zero Emissions Applications
> *www.ias.unu.edu/proceedings/icibs/bjorn/paper.htm*

> **The design of living technologies for waste treatment**
> by John Todd and Beth Josephson
> Internet Conference on Integrated Bio-Systems in Zero Emissions Applications
> *www.ias.unu.edu/proceedings/icibs/todd/paper.htm*

Internet Conference on Material Flow Analysis of Integrated Bio-Systems
www.ias.unu.edu/proceedings/icibs/ic-mfa/

> **Study of Agriculture-Aquaculture Ecological Economic System With Nutrient Flow Analysis (Surface Aquaponics)**
> by Song Xiangfu, et al.
> Internet Conference on Material Flow Analysis of Integrated Bio-Systems
> *www.ias.unu.edu/proceedings/icibs/ic-mfa/song/paperv2.html*

> **Phytoremediation of Aquaculture Effluents**
> by Paul Adler
> Internet Conference on Material Flow Analysis of Integrated Bio-Systems
> *www.ias.unu.edu/proceedings/icibs/ic-mfa/adler/index.html*

Wastewater- Fed Aquaculture Systems: Status and Prospects
by Peter Edwards
Aquaculture and Aquatic Resources Management Program, Asian Institute of Technology
www.aqua-information.ait.ac.th/aarmpage/Documents/Readings3New.pdf

World Fish Center
www.worldfishcenter.org

Ecological Engineering (Elsevier journal)
www.sciencedirect.com/science/journal/09258574

> *Ecological engineering has been defined as the design of ecosystems for the mutual benefit of humans and nature. Specific topics covered in the journal include: ecotechnology; synthetic ecology; bioengineering; sustainable agroecology; habitat reconstruction; restoration ecology; ecosystem conservation; ecosystem rehabilitation; stream and river restoration; wetland restoration and construction; reclamation ecology; non-renewable resource conservation.*

Wastewater-fed Aquaculture in Temperate Climates - Nutrient recycling with Daphnia and Fish
4th International Conference on Ecological Engineering for Wastewater Treatment, June 1999, Aas Norway
www.hortikultur.ch/pub/files/15.pdf

Appendix

Bibliography on Aquaponics

The following bibliography contains selected literature citations on aquaponics and integrated hydroponics-aquaculture published in trade magazines and scientific journals. Collectively, these articles provide an instant library on aquaponics. They are provided here as an important time saver to those seeking technical and popular information on this topic. University libraries carry scientific journals (e.g., *Aquaculture International, Aquacultural Engineering*) and trade magazines (*Aquaculture, Greenhouse Management and Production*), and they offer on-site photocoping services to library visitors. Inter-Library Loan is a service available through most local libraries, and can provide photocopies of articles for a small fee.

Please note *The Growing Edge*, *Aquaponics Journal*, and *Practical Hydroponics & Greenhouses* are the most relevant trade magazines for aquaponics, recirculating aquaculture, hydroponics, and related topics, including farmer profiles. However, they are relatively new and less widely distributed in university libraries. For a complete list of articles and back issues available through these trade magazines, see the publisher's Web sites:

The Growing Edge
www.growingedge.com/magazine/compindex.html

Aquaponics Journal
www.aquaponicsjournal.com/BackIssues.htm

Practical Hydroponics & Greenhouses
www.hydroponics.com.au/back_issues.html

North Carolina State University

McMurtry, M.R., et al. 1990. Sand culture of vegetables using recirculating aquacultural effluents. Applied Agricultural Research. Vol. 5, No. 4. (Fall). p. 280–284.

McMurtry, Mark Richard. 1992. Integrated Aquaculture-Olericulture System as Influenced by Component Ratio. PhD. Dissertation, North Carolina State University. UMI, Ann Harbor, MI. 78 p.

McMurtry, M.R., D.C. Sanders, and P.V. Nelson. 1993. Mineral nutrient concentration and uptake by tomato irrigated with recirculating aquaculture water as influenced by quantity of fish waste products supplied. Journal of Plant Nutrition. Vol. 16, No. 3. p. 407–409.

McMurtry, M.R., et al. 1993. Yield of tomato irrigated with recirculating aquacultural water. Journal of Production Agriculture. Vol. 6, No. 3. (July-September). p. 428–432.

McMurtry, M.R., D.C. Sanders, and R.G. Hodson. 1997. Effects of biofilter/culture tank volume ratios on productivity of a recirculating fish/vegetable co-culture system. Journal of Applied Aquaculture. Vol. 7, No. 4. p. 33–51.

McMurtry, M.R., D.C. Sanders, J.D. Cure, R.G. Hodson, B.C. Haning, and P.C.S. Amand. 1997. Efficiency of water use of an integrated fish/vegetable co-culture system. Journal of the World Aquaculture Society. Vol. 28, No. 4. p. 420–428.

Sanders, Doug, and Mark McMurtry. 1988. Fish increase greenhouse profits. American Vegetable Grower. February. p. 32–33.

The Speraneo System

Durham, Deni. 1992. Low-tech polycultural yields, high profit. Small Farm Today. June. p. 23–25.

Modeland, Vern. 1993. Aquafarming on a budget. BackHome. Summer. p. 28–31.

Modeland, Vern. 1998. The Ozarks' S&S aqua farm. The Ozarks Mountaineer. June-July. p. 42–44.

Modeland, Vern. 1998. Maturing marvel: S&S Aqua Farm. The Growing Edge. Vol. 9, No. 5 (May-June). p. 35–38.

Rich, Doug. 1998. Closed system opens markets. The High Plains Journal. Vol. 115, No. 34. August 24. p. 1–A.

Smith, John Wesley. 1993. The genius of simplicity. The Growing Edge. Vol. 5, No. 2. (Fall). p. 40–44, 70.

Thompson, Nina. 1993. Fish + plants = food. Missouri Conservationist. August. p. 28.

Yarrow, David. 1998. A food production revolution: Missouri aquafarmers discover huge benefits in trace elements integrated with hydroponics. Remineralize the Earth. Spring-Fall, No. 12-13. p. 38–43.

The Rakocy System and Related Papers

Rakocy, J., R.C. Shultz, D.S. Bailey, E.S. and Thoman. 2004. Aquaponic production of tilapia and basil: comparing a batch and staggered cropping system. Acta Horticulturae. Vol. 648. p. 63–69. *www.actahort.org/books/648/648_8.htm*

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