An Integrated Fish Culture Hydroponic Vegetable Production System

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Interest in linking intensive, closed system fish culture with hydroponic vegetable production continues to expand, particularly in cool temperature climates where greenhouse food production can provide year-round sustained yields of fresh produce. A newly revised design has overcome a number of the problems in previously tested systems when proven chemical hydroponic designs were combined with intensive fish culture systems. The success in the new design has resulted in solving the difficulties associated with the build-up of organic solids and the development of anaerobic conditions around the root systems of the vegetable produce. It further eliminates the need for the addition of separate biofiltration, water clarification components, and/or the plumbing required to connect system components together.

Design Criteria

The basic strategy behind the concept is to maximize the number of functions of each of the system's biological components to improve economic performance. If the area within a greenhouse can be used for several income generating or cost reducing functions, the investment for the greenhouse -structure itself and housed system components are minimized per unit output. Integrated fish culture and hydroponics fit these criteria well.

Solar Aquaculture

In greenhouse systems, water is an excellent medium for the collection and storage of solar energy, thus an aquaculture system can function as a passive solar collector and heat storer in solar architecture. Calculations are available which determine the volume of water required to maintain desired temperatures for solar heated greenhouses within specific climatic conditions. In such a system, the water is also used for fish, culture, and the resultant fertility from fish wastes are used, for hydroponic plant production. This is an excellent means of resource recovery, energy conservation, and, maintenance of high water quality for active fish growth.

Integrated System Design

The objectives in the system design are to minimize investment capital and operations costs while concurrently maintaining stable, reliable, economically sound food production.

The design uses the solar-algae pond as the main structural element (See Figure I and Photo A). Solar-algae ponds (translucent 'fiberglass silos 1.5 m. in diameter and height are available from the Kalwall Manufacturing Company in Manchester New Hampshire. These ponds function as excellent passive solar collectors by allowing sunlight to enter through their sides and be directly absorbed and converted to heat within the water column. Measurements have shown that a single pond can absorb and release aboutc6,300 kcal per day during mid winter' on Cape Cod, Massachusetts. The phytoplankton in the water column absorbs and converts most of the light to heat that enters the pond water and also provides some daytime oxygenation through photosynthesis. Aeration can eliminate all reliance upon photosynthetic oxygenation when non-phytoplankton feeding aquatic organisms are cultured.

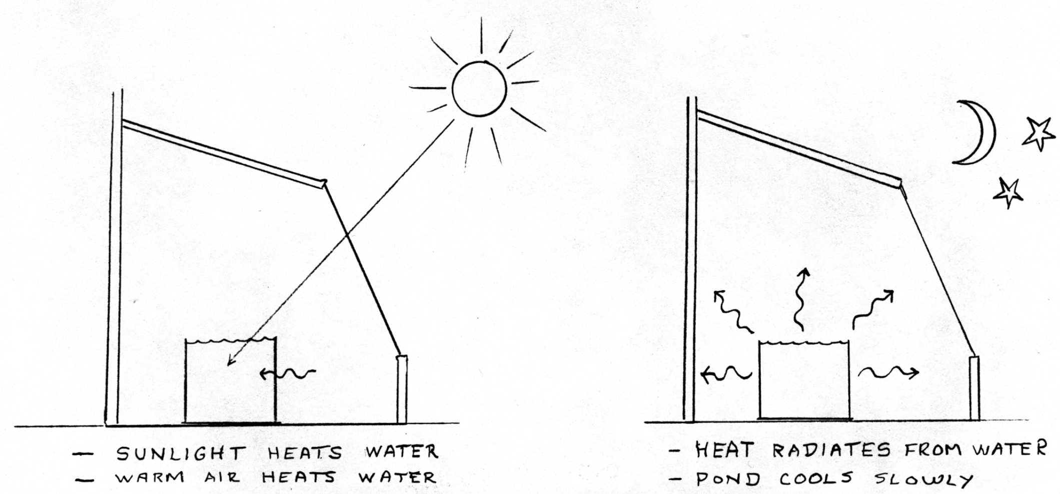
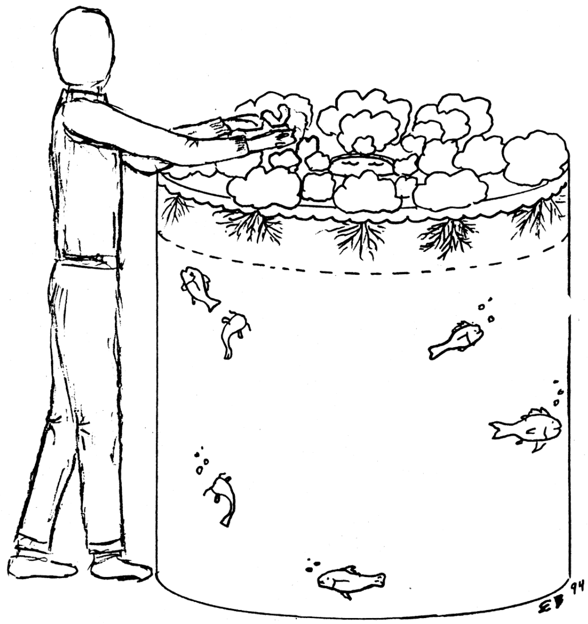


Figure 1 Integrated Hydroponics Fish Culture System



A. Hydroponic vegetables on top of pond.
B. Styrofoam flotation and guides for plants.
C. Central core opening for fish feeding.
D. Mesh cage to **prevent fish from eating plant roots.**
E. Fish rearing area in pond.

Fish are grown in the lower portion of the silo with a floating hydroponics system occupying about 15% of the water volume at the, top. The 0.6 cm plastic mesh cage with a depth of 20 cm. protects the plant roots from being disturbed or eaten by the fish. The central core opening (30 cm diameter) makes it possible to directly feed the fish. Fish vitality and health can also be judged by the voracity of their daily feeding in the central core area.

The fertile fish wastes in the pond water are thus directly accessible to the plant roots. The closed-cell styrofoam floating on the surface of the ponds supports the plants, helps insulate the water from heat loss, and reflects additional light to the plant's leaves. The radial channels between each of the eighteen trapezoidal pieces of foam are 2.5 cm wide by 60 cm in length, through which the plant roots have access to the water. The I to 2 cm air space above the water surface created by the styrofoam has been proven beneficial for hydroponic vegetable production by preventing root rot. (See Photo 2.)

The increasing area from the central core to the outer rim of the pond is., also advantageous, particularly for lettuce growth. This geometry allows for six lettuce plants to be mounted over each of the eighteen channels. Young two-week old seedlings are placed over each channel at the inner core each week. They are moved outward each week with a new group of eighteen seedlings being installed at the inner core. After six-weeks on the pond, the plants (with maximum area available to them at the outer rim) are at market size - about 450 gm with a diameter of about 25 cm.

Three small aquarium air diffusers should be suspended equidistant from each other around the pond circumference 15 cm from the bottom to provide oxygen for the fish and plant roots as well as to cause a gentle upwelling of aerated, fertile water through the pond. This improves the availability of nutrients and oxygen to the plant roots. The plant roots have a second major function as water clarifiers. The plant roots collect suspended detritus, thereby helping to maintain high water transparency. When the plant is harvested, the root systems are fully developed and have captured a significant quantity of detritus. The detritus removal further reduces the accumulation of BOD in the system and excess build-up of organic matter. The roots also function as a substrate for nitrifying (Nit rosomonas and Nitrobacter) bacteria which control and convert dissolved ammonia to nitrate which is then taken up by the plants.

The plant roots further become a habitat for zooplankton, nematodes, and midge larvae which consume the detritus on the roots. Dense clodoceran, copepod, midge larva, and nematode blooms were observed among the roots and probably developed as a result of the fish being restricted from preying upon them in the root cage area. With water movement created by the aeration, these organisms are most likely made available to the fish as recycled feeds when they leave the root masses. The emerging adult midges can also be captured with a nocturnal bug light and fed back to the fish, particularly in greenhouse systems.

System Operation

The most critical aspect for efficient operation of an integrated fish culture/hydroponics design lies in the proportioning of the two respective components. The fish wastes must be sufficient to provide a majority of the nutrient-base for the plants, and, concurrently, the hydroponic component must be scaled to take up effectively the resultant fish wastes to maintain sufficiently high water quality for active fish growth at an optimal feeding rate.

Research results have indicated that the system can be precisely. managed. The feed nitrogen conversion efficiently using commercial pellets to fish growth is about 37.4% (an S Conversion of 1.7) for the all-male population of blue tilapia, *Oreochromis aureus,* used in the study. The remainder is released to the pond wat er. On a dry weight basis for hydroponically grown Buttercrunch lettuce, the organic matter removed at harvest including leaves, roots, and captured detritus contains approximately 4.5%-N. At market-size, the harvested, live plant with roots and detritus is about 90% water and weighs approximately 450 g which equals 2.02 g-N. A harvest of 18 heads of lettuce per week amounts to a total 8.1 kg wet weight or 810 grams dry weight. This equals 36.4 g-N uptake per week.

To provide the nitrogen for weekly lettuce harvests of 18 heads at full production, the fish would have to be fed 990 g/week (165 g/day for 6 days/week) of Purina Trout Chow (PTC) which is about 5 9% N, equalling an input of 58.2 g-N/week. (Other feeds can be used if the feed conversion efficiency and nitrogen content are known.) With the fish fed at the rate of roughly 3% of their live weight daily, each 2300 liter solar-algae pond would require an average minimum weekly population of 5.5 kg tilapia (5.2 to 5.8 kg), allowing for a weekly tilapia growth of approximately 580 g. These fish can be maintained at a higher density for monthly harvesting operations. However, the feed rate should not exceed 990 g-PTC/week of PTC regardless of the total, live weight of the fish population because the water quality will degrade. (See Tables I and 2 for fish stocking and growth data comparing integrated systems with a control which did not have the hydroponic lettuce production component). To harvest the fish, the entire hydroponics apparatus can be lifted out of the pond to allow for easy netting.

1985 FISH CULTURE/HYDROPONICS TRIALS

Ponds I - 4 with Hydroponics Pond 14 - Control

TABLE 1. FISH STOCKING IN SOLAR-ALGAE PONDS

Pond Number	**Fish Number**	**Total Biomass**	**Average Biomass**	**Date**
1	95	2500 g	26.3 g	2/27
2	.90	2500 g	27.7 g	2/27
3	135	2500 g	18.5 g	2/26
4	123	2500 g	20.3 g	2/26
1-4 (ave.)	111	2500 g	23.2 g	
14	129	2500 g	19A g	2/26

1985 FISH CULTURE/HYDROPONICS TRIALS

(Oreochromis aureus o)
Ponds I - 4 w/Hydroponics **Ponds 14 - Control**
Table 2. Fish Growth Data 2/27 - 5/3

Pond	*'Total (Weighed) Fish	Biomass (g) Total(Weighed)	Total Growth [N to fish] (g)	Date
1	95(80)	5069(4269)	2569 [97.6]	5/3
2	90 (85)*	4496(4246)	1996 [75.8]	5/6
3	135(126)	4355(4065)	1855 [70-51	5/6
4	123(116)	4568(4307)	2068 [78.61	5/6
Ave. I - 4		4622(4222)	2122 [80.6]	
14	129(126)	4556(4485)	2056 [78.1]	5/4

**Includes 2 mortalities retrieved during weighing*

1985 FISH CULTURE/HYDROPONICS TRIAL

(Oreochromis aureus 0)
Ponds I - 4 w/Hydroponics Pond 14 - Control

TABLE 3. FEED CONVERSION EFFICIENCY 2/27 - 5/3
TOTAL FEED IN ALL PONDS

Purina Trout Chow	3250 g	(36% Protein-5.9% N)
Blue Seal Rabbit Feed	730 g	(20% Protein-3.2%N)

TOTAL 3980g **(Total N = 215.1g)**

FEED CONVERSION RESULTS

Pond Number	FCR*	N Conversion to Fish Biomass (%)
I	I A	45.4
2	1.8	35.2
3	2.0	32.8
4	1.8	36.5
Ave. 14	1.7	37.4
14	1.8	363

**Food conversion ratio (live fish/dry feed)*

Hydroponic Production Sequence for Lettuce

Buttercrunch lettuce was the primary crop tested during the project. Lettuce seeds were put in 3.8 cm peat pots saturated with fish pond water for one week. After germination and the emergence of the seedlings, the peat pods were put into 5 x 5 cm styrofoam floats with 5 mm holes in the' bottom to allow root growth into the pond water which is maintained at a 3 cm depth in seedling trays. At tile end of the second week, the styrofoam floats with seedlings bridge tile 2.5 cm channels radiating outward in the floating hydroponics unit. The exposed roots. thereby dip into the pond water of the protected root cage volume beneath. Every week tile process is repeated. with the entire row of' plants moved outward with tile addition of the new seedling at the inner core. At the end of the sixth week, tile first 18 lettuce plants mounted oil tile pond have reached tile pond's outer circumference and are ready for harvest. Every week thereafter, 18 new seedlings are added and 18 mature lettuce heads are liarvested.

Other Hydroponic Plant Options

Cucumber and tomatoes were also interplanted and evaluated with lettuce in the system. They showed good growth and fruit production. One possible drawback for these type of plants noted from a qualitative observation was that roots of these plants grew into large masses which remained in the pond for two or three times longer than that of the lettuce. The result was that the interior of the root masses apparently became anaerobic. There wasn't any evident effect upon the plants' productivity, but it is postulated that in times the release of anaerobic by-products might ultimately have an adverse affect on fish growth.

To improve the economic performance from a commercial standpoint, ornamental flowers might also be cultivated which can improve the income potential between 5 to 10 times.

Water Quality Control

Figure 2 A through 2 D represent the water quality in ponds with the hydroponic raft installed and show rather consistent results in chemical and turbidity fluctuations among the hydroponic ponds. As can be seen during the first month, the nitrifying bacteria become established resulting in the conversion of almost all the ammonia and nitrite to nitrate. The nitrate levels in all hydroponics ponds peak during the fourth week. From that time onward, sufficient plant growth is attained to assimilate and remove nearly all available dissolved nitrate leaving it at concentrations between 1-2 mg/l. There is considerably more fluctuation of the nitrogen and transparency factors in the control pond (Pond 14) presented in Figure 2E. Nylon stocking filters mounted on 3.8 cm air diameter lift pumps were used to capture detritus and they were effective during the first month after which the established plant root systems predominantly clarified the pond water. They were removed from Ponds 2, 4, & 14 toward the end of the second month. Photo illustrates the mass of detritus captured by the roots.

System Adjustments

To maintain a proper nutrient balance in the ponds for the vegetable growth, some care must be taken to ensure that sufficient micro-nutrients are available. Plant difficiencies in iron and magnesium were observed during the study. Others are adequately available in PTC. During the evaluation period, 20% of the N in the fish diet was made up of rabbit feed which is high in iron. (Blue Seal rabbit feed contains 3.2% N by dry weight.) Rabbit feed was suitable for this purpose since tilapia readily consume it. To resolve the magnesium defficiency, 500 g of dolomite (magnesium-rich) limestone was added to each pond. In addition, 500 g of powdered, garden-variety limestone was put into the ponds on a weekly basis to maintain high alkalinity, assuring good decomposition and nitrification in the pond water. As a result, it can be seen in Figure 2 that the total alkalinity concentration in all ponds constantly increased to 80-90 mg/l during the monitoring period. Morning pH and dissolved oxygen levels as well as turbidity and temperature may be seen in Figure 3.

Air pruning of the seedlings was a rare occurrence; however, when it did occur, a 2 x 10 cm swatch of blotter paper was used as wick for the seedling roots to grow down initially until they reached the water as shown in Photo F.

Use with Other Systems and Applications

In addition to growing pan-size fish, the fish culture component *of* the integrated system can be used for rearing *of* fry to fingerling-size fish over winter months for stocking cages or ponds for summer grow-out. Clams for food or freshwater pearl production can be included in the design by stocking them in the root cage. Aquarium fish such as goldfish can be grown in the system in addition to other food fishes including catfish. Effluent from fish hatcheries might also be run through the hydroponics system for resource recovery and water purification prior to discharge into the environment.

Economically, the system described above has a significant rate of return for food production at the household scale outdoors during summer and within home greenhouses for year-round yields. Commercial applications are being investigated including installations for restaurants, For wholesale purposes, modification of system design may be required to reduce labor costs and also include the cultivation of higher valued products such as ornamental fish and plants.

ABOUT THE AUTHOR

1986. Ronald D. Zweig is President of Eco Logic, P.O. Box 1440, North Falmouth, Massachusetts 02556, U.S.A. Zweig will be an instructor of the "Integrated Aquaculture Systems Course" at the Woods Hole Oceanographic Institute, May 23,1986.

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