# Greenwater Tank Culture of Tilapia

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ABSTRACT

Greenwater tank culture of tilapia is an appropriate method for producing commercial levels of tilapia in locations that have environmental constraints such as limited land and water (e.g., U.S. Virgin Islands) or sub-optimal temperatures, where a greenhouse would be used to control temperature. High densities and feeding rates can be maintained through continual aeration and solids removal. Ammonia is removed by phytoplankton uptake and through nitrification on suspended organic particles within the water column. These four treatment processes maintain good water quality, reduce the need for water exchange and maximize water use efficiency. Phytoplankton and other organisms within the water column are grazed on by tilapia, thereby recycling waste nutrients and lowering feed conversion ratios. A greenwater tank system for tilapia culture was developed in St. Croix. It consists of a 31.0-$m^3$ rearing tank (culture volume) and a 1.4-$m^3$ clarifier from which solids are removed twice daily. The rearing tank is continually aerated with 13 air stones and a 1/20-hp vertical lift pump. An experiment with Nile tilapia (Oreochromis niloticus) stocked at 26 fish/$m^3$ and fed 32% protein feed for 24 weeks attained a final biomass of 13.4 kg/$m^3$, a feed conversion ratio of 1.41 and a survival rate of 99.3% while exchanging only 0.23% of the rearing tank volume per day. From another experiment, solid waste was used to irrigate and fertilize a field of pak choi (Brassica rapa), achieving a production level comparable to that obtained with inorganic fertilizers. Land application of sludge increased the organic content of the soil as well as provided nitrogen and phosphorus. Greenwater tank culture of tilapia is an intermediate technology that is easy to learn and manage. Some preliminary economic calculations indicate that this system has profit potential due to its high productivity and reasonable capital and operational costs, which makes greenwater tank culture appropriate for widespread application.

KEY WORDS: Greenwater tank culture, tilapia, water quality

## INTRODUCTION

In the U.S. Virgin Islands, the local reef fish population is fully exploited, and consumed wholly within the territory. There are no exports. On the contrary, the territory imports at least three million pounds (1,360,000 kg) of seafood annually (personal communication, William J. Tobias, Department of Planning and Natural Resources, USVI). Aquaculture could help to alleviate the seafood deficit, as well as provide a means of income for the local population.

St. Croix is a semi-arid, tropical island with limited freshwater resources, and therefore, traditional pond aquaculture is impractical. Consequently, the University of the Virgin Islands Agricultural Experiment Station (UVI-AES) has concentrated on developing intensive tank culture systems, one of which is greenwater tank culture of tilapia. An experimental system consists of a 31.0-$m^3$ rearing tank (culture volume) and a 1.4-$m^3$ clarifier from which solids are removed twice daily. The rearing tank is continually aerated with 13 air stones and a 1/20-hp vertical lift pump (Figure 1).

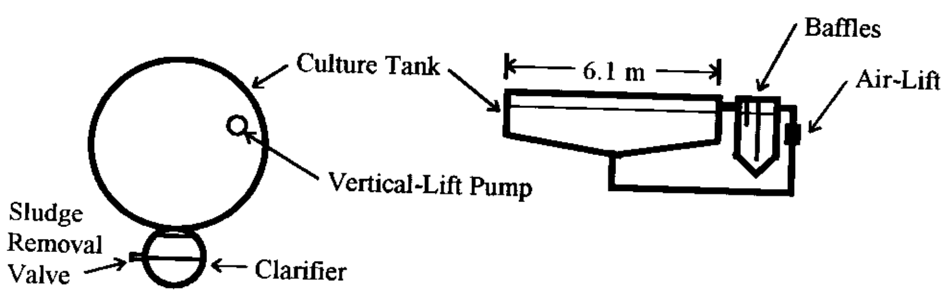


**Figure 1.** Top and side view of greenwater tank culture system.

## FISH PRODUCTION METHOD

In aquaculture, the major factors limiting production are fish nutrition, dissolved oxygen concentrations and waste product accumulation. Within the greenwater tank culture system, fish are fed a nutritionally- complete (32% protein), pelleted feed to near satiation twice daily. A vertical lift pump and air stones maintain dissolved oxygen concentrations above 4 mg/L. Nitrogenous waste products are removed by phytoplankton uptake and microbial biosynthesis, the latter being of greater importance. In the greenwater system suspended organic matter and plankton are in constant circulation, creating a suspended growth treatment process wherein nitrifying bacteria (*Nitrosomonas* and *Nitrobacter* spp.) oxidize toxic total ammonia nitrogen (TAN) to relatively harmless nitrate ($NO_3^-$) and heterotrophic bacteria proliferate. Besides maintaining appropriate water quality for fish culture, this process also creates microbial proteins that are grazed upon and utilized for nutrition by the fish themselves (Schroeder and Serfling 1989, Kochba et al. 1994, Avnimelech et al. 1994). Additionally, the culture water is constantly circulated through a clarifier at a rate of 20 L/min, which produces one complete circulation of the culture volume every 24 hours. As the water moves under the baffles within the clarifier, its flow becomes laminar, enabling solid particles to settle to the bottom. Twice daily this sludge is drained from the clarifier, removing feces, detritus, bacteria and senescent algae. Solids removal reduces the biochemical oxygen demand (BOD) of the culture water and encourages continued algae and bacterial population growth, which further improves water quality.

What makes greenwater tank culture of tilapia so unique is its hybridization of traditional pond culture principles, which are extensive and resource consumptive, and those of indoor recirculating systems, which are hyper-intensive and resource conservative. There are reports of only a few systems around the world which employ a similar technology (Table 1).

Greenwater tank culture of tilapia is performed using various tank sizes and shapes, filtering methods and feeding strategies. However, all forms of greenwater tank culture have the same goals: high production levels, maximum nutrient utilization and minimal water discharge, the latter becoming increasingly important.

**Table 1.** Various greenwater tank culture systems with important culture parameters (mean values).

| **Reference** | Cole et al. 1997 | Personal communication, Jim Kahle. President and General Manager of Solar Aquafarms, Niland, CA | Personal communication, Greg Lutz, Extension Specialist, Louisiana State University |
|---|---|---|---|
| **Fish species** | *Oreochromis niloticus* | *O. mossambicus* and *O. niloticus* | *O. niloticus* and *Cyprinus carpio* |
| **Stocking rate (fish/m³)** | 2 | - | - |
| **FCR** | 1.41 | 1.6 - 1.7 | 1.8 |
| **Growth rate (g/day)** | 2.64 | - | - |
| **Daily sustainable feeding rate (g/m³)** | 1.33 | 3.60 | - |
| **Survival (%)** | 99.3 | - | 94 |
| **Carrying capacity (kg/m³)** | 13.4 | 24 | 26.4 - 37.1 |
| **Method of Solids Removal** | Clarifier | Proprietary | Bead filters |
| **Rate (% tank volume/day)** | 0.23 | 0.17 | 0.1 - 2.4 |
| **Notes** | - | System is divided into four culture tanks and one "bioconverter" tank | Tanks are located in greenhouses |

**Table 1 (cont.)** Various greenwater tank culture systems with important culture parameters (mean values).

| Reference | Yoram Avnimelech, Israel Institute of Technology | Avnimelech *et al.*, 1994 | Avnimelech *et al.*, 1994 |
|---|---|---|---|
| **Fish species** | *O. niloticus* x *O. aureus* and red tilapia | *O. niloticus* x *O. aureus* | *O. niloticus* x *O. aureus* |
| **Stocking rate (fish/m³)** | - | 78 | 64 |
| **FCR** | 1.5 | 3.4 | 2.9 |
| **Growth rate (g/day)** | - | 1.57 | 1.95 |
| **Daily sustainable feeding rate (g/m³)** | 360 | 296 (150 g of feed and 146 g of wheat flour) | 296 (150 g of feed and 146 g of wheat flour) |
| **Survival (%)** | - | 85.4 | 96.0 |
| **Carrying capacity (kg/m³)** | 20 | 12.84 | 16.20 |
| **Method of Solids Removal** | Water pumped from center drain into sedimentation pond and then returned | Water pumped from center drain into sedimentation pond | Water pumped from center drain into sedimentation pond |
| **Rate (% tank volume/day)** | 10 | 20 | 20 |
| **Notes** | Standard fish pellets supplemented with additional carbon source | 51-day experiment | 30-day experiment |

## LAND APPLICATION OF SOLIDS

The National Pollutant Discharge Elimination System (NPDES) was created as part of the Federal Water Pollution Control Act of 1972. Under the Act, the discharge of pollutants from "point sources" is prohibited unless the discharge is authorized by an NPDES permit, or in the case of the U.S. Virgin Islands, a Territorial Pollution Discharge Elimination System (TPDES) permit (Tucker 1998). To avoid the need for an NPDES permit, aquaculturists have employed a variety of techniques to manage their production wastes, one of which is crop irrigation. Table 2 describes some of these endeavors.

Aquacultural sludge is a source of available nitrogen and phosphorus, and to a lesser extent, potassium. It also increases soil fertility by increasing organic matter and has moderate neutralizing capacity in strongly acidic soils (Willet and Jakobsen 1986). Cole et al. (1995) and Mazzarino et al. (1997) found application of aquacultural sludge to be superior to traditional inorganic fertilization regimes for growing pak choi and ryegrass, respectively, while Olson (1992) found aquacultural sludge to perform as well as commercial fertilizer in the production of sweet corn and spring wheat. Their results depended on the method and rate of application of the sludge. Aquacultural sludge also contains no weed seeds, a common problem with manure (Olson 1992). Most importantly, by utilizing aquacultural sludge for terrestrial crop irrigation and fertilization, a waste product is being used for beneficial purposes instead of being discharged to the environment where it may have adverse effects. The application of aquacultural sludge is not without problems. When sludge dries, it may be malodorous and often forms a crusty surface (Olson 1992). Transporting and applying the sludge uniformly is expensive and difficult. The exact chemical composition and fertilization value of sludge is variable and depends on many factors including fish species, feed quality, culture method, collection method and the condition and length of storage. Nonetheless, considering the benefits derived from sludge application, coupled with the costs involved for alternative disposal, agricultural application of aquacultural sludge is an appropriate practice.

**Table 2.** Results of various aquacultural sludge irrigation experiments. The values represent means.

| **Reference** | Cole *et al.*, 1995 | Bergheim *et al.*, 1993 | Willet and Jakobsen, 1986 |
|---|---|---|---|
| **Fish species** | *O. urolepis hornorum* and *O. mossambicus* (Florida-red tilapia) | *Salmo salar* (Atlantic salmon) | *Oncorhynchus mykiss* (Rainbow trout) |
| **Culture unit** | Greenwater tank culture | Single-pass tanks | Concrete-lined pond |
| **Concentration method** | Clarifier | Microscreen filtration (60 (m), then settling basin | Dredged from bottom |
| **Sludge application method** | Drip irrigated once per week to maintain soil moisture tension at 20 kPa | - | 28 mt/ha incorporated into the surface 100 mm by hand cultivation |
| **Nutrient content of sludge** | Inorganic N=45.68 mg/L, Total P=107.08 mg/L, K=52.8 mg/L | Total N=2-5 g/L, Total P=1-3 g/L, Total organic C=12-16 g/L, Dry matter=5-10% | N=3.30%, P=1.03%, K=0.03%, Organic C=25%, Dry matter=37% |
| **Crop** | *Brassica rapa* (pak choi) | - | *Medicago sativa* (lucerne) |
| **Growth result** | 26.1 t/ha/crop (exp. 1) 47.4 t/ha/crop (exp. 2) | - | 805 g/m$^2$ dry matter yield (harvest 2) |

**Table 2 (cont.).** Results of various aquacultural sludge irrigation experiments. The values represent means.

| **Reference** | Mazzarino *et al.*, 1997 | Olson, 1992 | Olson, 1992 |
|---|---|---|---|
| **Fish species** | *Oncorhynchus mykiss* (Rainbow trout) | *Oncorhynchus mykiss* (Rainbow trout) | *Oncorhynchus mykiss* (Rainbow trout) |
| **Culture unit** | Cage culture | Raceway culture | Raceway culture |
| **Concentration method** | Dredged from top 10 cm of sediment under 3-year old farm | Vacuumed from a settling basin at the end of the raceways | Vacuumed from a settling basin at the end of the raceways |
| **Sludge application method** | Mixed 80 mg/ha of sludge with 1.5 kg of soil into greenhouse pots | Sludge was dried and mixed into 45-L greenhouse pots at a rate of 336 kg/ha | Applied to field at 673 kg/ha with spreader truck, then plowed under |
| **Nutrient content of sludge** | Total N=3.0 g/kg, Total P=16 g/kg, Total K=7.6 g/kg, Organic C=39 g/kg | Total N=4.13%, P=2.15%, K=0.34% Dry matter=12% | Total N=4.13%, P=2.15%, K=0.34% Dry matter=12% |
| **Crop** | *Lolium perenne* (ryegrass) | Borah spring wheat | Sweet corn |
| **Growth result** | 10.2 g/pot dry matter yield | Seed=15 g/pot Straw=19 g/pot | 112 kg/ha corn yield |

## FUTURE RESEARCH

The UVI-AES greenwater tank culture system has been very successful at intensively raising tilapia while maximizing water and nutrient use efficiency. However, to make the system more appealing to potential investors, production levels must be increased and/or production costs must be lowered, to increase the rate of return on investment. Currently, production ceilings have been reached due to water quality limitations. Fish stop eating when dissolved oxygen, nitrites or nitrates reach sub-lethal levels. These constraints must be removed without significant increases of management complexity or capital costs.

Dissolved oxygen becomes a limiting factor when decomposition of organic matter within the culture water exhibits a greater biochemical oxygen demand (BOD) than can be met by the current aeration system. The solution is to remove excess organic matter. However, the suspended organic matter acts as a substrate for nitrifying bacterial growth. Therefore, only a portion of it must be removed. The proposed solution is to regularly add an optimum dose of coagulant to the system. Smaller particles will clump together and be removed by the clarifier, effectively decreasing BOD in the system. Two such coagulants have been proposed, aluminum sulfate (alum) and cationic polymers. Chesness et al. (1976) tested alum and several commercial coagulants on channel catfish (*Ictalurus punctatus*) raceway effluents. Although they found the results unsatisfactory for raceway effluent, alum was superior and cheaper than any other coagulant tested at removing turbidity. Boyd (1979) also found alum to be effective at removing clay turbidity from ponds. We are currently experimenting with weekly alum application concentrations of 25.8, 38.7 and 51.5 mg/L. Thus far, we have achieved a daily sustainable feeding rate of 226 g/$m^3$ (culture volume) with the highest concentration, an increase of 70% from previous studies at UVI-AES.

The production of toxic nitrogenous compounds are an inevitable by-product of the greenwater tank culture system. Total ammonia nitrogen (TAN), nitrite ($NO_2^-$) and nitrate ($NO_3^-$) can all accumulate within the culture environment, causing reduced production or even death. A number of solutions have been proposed to deal with these problems. One which will act upon all three compounds, but has its greatest affect on TAN, is to add a carbonaceous substrate to the culture tank to promote microbial protein biosynthesis. Avnimelech et al. (1994) obtained reasonable success culturing tilapias by reducing feed inputs to 50% of that normally applied in an intensive culture system and matching that feed input with a carbonaceous substrate (i.e., wheat flour) to maintain a carbon:nitrogen ratio of 15:1. This enables nitrifying bacteria to continuously bind nitrogen in the formation of cell proteins, thus improving water quality and providing a supplemental protein source for the fish (Avnimelech et al. 1989). To control nitrite toxicity, calcium chloride may be added to the culture environment to maintain a $Cl^-:NO_2^-$ ratio of 6:1. To remove nitrate, a simple denitrification component can be added to the system. A denitrification unit can be created by having a portion of the water flow through a 0.85 $m^3$ rectangular tank which is filled with standard orchard netting. Anaerobic pockets form within the netting, creating areas for denitrifying bacteria to colonize. As water flows through these pockets, nitrate is reduced to nitrogen gas, which is expelled from the system in a heavily aerated degassing zone before water returns to the rearing tank. Other aquaculture systems on the experiment station have been using this technology with great success.

Although a detailed economic analysis of the greenwater tank culture system has not been completed, preliminary calculations indicate a profit potential, especially considering economies of scale. UVI-AES has plans to build a 200 $m^3$ greenwater culture system in the near future that will produce a yield of 5 mt of tilapia per crop. Because of the year-around optimum culture temperatures in the Virgin Islands, two crops can be produced per year bringing the total annual yield to 10 mt of tilapia, a level that is 100 times greater than the annual production of traditional pond culture, using an equivalent volume of water!

Greenwater tank culture of tilapia is an intermediate technology that is easy to learn and manage. Studies at UVI-AES have shown that tilapia can be intensively cultured in this system with minimal water use and high nutrient utilization. An important by-product of greenwater tank culture is a nutrient and organically rich sludge which can successfully be applied to various terrestrial crops as a source of irrigation water and fertilizer. It is hoped that Virgin Islanders will embrace this technology and reap the benefits of fresh fish, nutritious plant crops and supplemental income.

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