A DEMONSTRATION OF TILAPIA AND TOMATO CULTURE UTILIZING AN ENERGY EFFICIENT INTEGRATED SYSTEM APPROACH

JCHAPPELL J. A. [1], T. W. BROWN[2] AND T. PURCELL[2]

1. *Associate Professor, Auburn University, Department of Fisheries and Allied Aquaculture*
2. *Students, Auburn University, Department of Fisheries and Allied Aquacultures*

Abstract

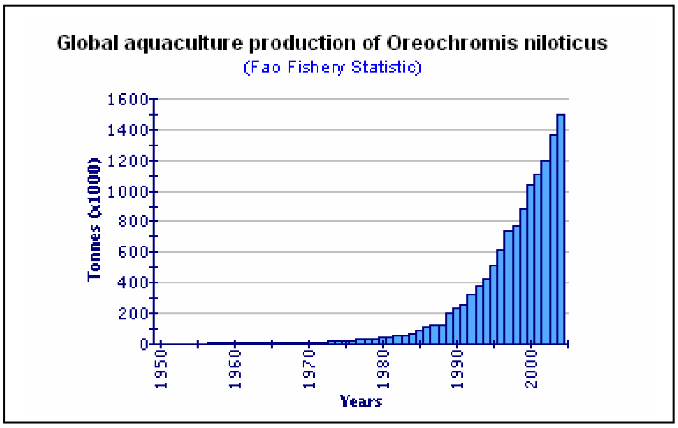
Recent research and demonstration efforts which were supported by Alabama Cooperative Extension System and the Alabama Agricultural Experiment Station through the Black Belt Initiative and the Alabama Catfish Producers Association enabled some new developments in aquaculture production technology. First, in a project focused on use of alternative energy and energy conservation, a controlled environment aquaculture project was undertaken which used shelled corn and wood pellets as fuel for winter heating two greenhouses. One greenhouse was equipped with a simple fish production system comprised of two elongated, plywood and plastic lined tanks which held a total volume of about 55,000 gallons of water. No bio-filter structure was used. Life support was provided by 2 Sweetwater blowers of 1.5 H.P. each and a very low level (1-6%) daily water exchange. The second greenhouse was set up to produce plants and initially greenhouse tomatoes were cultured. The culture media was composted cotton gin waste placed in troughs excavated in the substrate soil. Two tomato cultivars were planted (Geronimo and Blitz) as transplants in October at a total of 600 plants in the 30 x 96 foot house. Fertilizers were applied pre-plant and subsequently on an as needed basis. Irrigation was provided both from a nearby rain-filled reservoir and water being removed from the fish house as water was exchanged. The fish system allows production of 10-12 tons of Tilapia per annual cycle. This equates to 350-400,000 pounds per acre per year. Tomato production was similarly robust at about 10,000 pounds per cycle. Two cycles per year would normally be cultured so about 10-12 tons per greenhouse of this size per year. This computes to 300-360,000 pounds of tomatoes per acre per year.

INTRODUCTION

Nile tilapia (*Oreochromis niloticus*) has been cultured for more than 3,000 years and are one of the first fish species to be cultured. All tilapia are native to Africa and the Middle East, even though there has been a worldwide distribution within the past sixty years due to aquacultural demands (Popma and Masser, 1999). Tilapia is a light-colored mild fish that is usually sold in restaurants and grocery stores as a filleted product, but there is also a market for whole fish at ethnic grocery stores. U.S. tilapia imports have surged more than 250% higher from the year 2000 to 340 million pounds (product-weight basis) in 2007. The value of the imports also increased

310% higher, respectively. China supplied 56% of the total tilapia products (frozen whole and frozen tilapia fillets) imported into the United States in 2005. With the increasing demand for tilapia, production will continue to expand as the market for tilapia grows (figure 1). The main constraint that has limited the growth of tilapia production in the US are the dependence of a fish production system on seasonal climate conditions.

Figure 1. Source: FAO Fishery Statistics



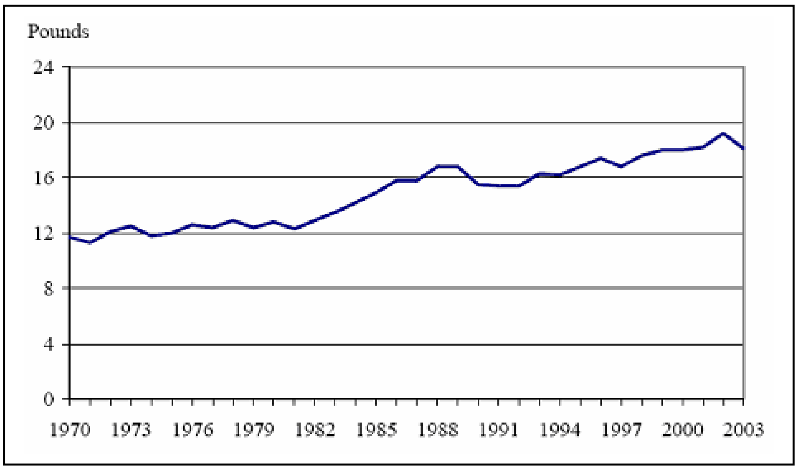
The total per capita consumption of fresh tomatoes has increased to 19.2 pounds in 2003 from 12.3 pounds in 1981 (figure 2). In 2004, the U.S. fresh market for tomato production was valued at $1.3 billion. Imports have made up a very large portion of the tomato consumption in the U.S. The U.S. fresh imports of tomatoes reached $900 million in 2004 with $750 million coming from Mexico.

Nile tilapias are an omnivorous grazer that feeds on phytoplankton, aquatic plants, small invertebrates, detritus, benthic fauna and bacterial films. They filter feed by entrapping suspended particles, including phytoplankton and bacteria on mucous in the buccal cavity. Even though Nile tilapia have the fastest growth rate of the *Oreochromis* genera, they reach sexual maturity in ponds by 5-6 months after stocking fry and spawning can occur when water temperature reaches 24^{o} C (Popma and Masser, 1999). This is a disadvantage when producing mixed-sex food fish to a desired market size (1 lb. Plus).

Intensive tank culture of tilapia offers several advantages over pond culture especially if warm water is unavailable year round and sufficient land/water is not available. High fish densities in tanks can disrupt their breeding behavior and allow both sexes of tilapia to be grown together to a marketable size. Mono-sex (all-male) stocks made available by several hatchery methods have distinct advantages over mixed-sex stocks. Tanks also allow the culturist to manage stocks more efficiently and allow a relatively high degree of environmental control over many parameters such as water temperature, dissolved oxygen, pH, and many excreted by-products that are normally undesirable (Rakocy *et al*, 1992). Feeding and harvesting practices are more efficient and require less time and labor (Rakocy, 1989).

Figure 2. U.S. Per-Capita Consumption of Fresh Tomatoes, 1970-2003

Source: USDA Economic Research Service



Tilapias have a lethal lower thermal limit of 11-12° C and perform best in culture at temperatures above 30° C (Lutz *et al,* 1998). Producing tilapia in a sub-tropical or temperate environment brings about economic considerations for the farmer that need to be resolved in an economically feasible manner in order to culture them economically and profitably. A greenhouse culture system, set up appropriately, allows the capture of renewable solar energy by storing heat energy from the sun during the day in the fish tanks which greatly reduce or eliminate some of the demand for heating during cold winter weather. A large expenditure to the farmer is feed, which accounts for 40-60% of the total production costs. Only 35-40% of the feed consumed by the fish is assimilated and turned into fish flesh while the rest (60-65%) is excreted into the water column. A way to improve this energy and nutrient loss is to utilize a fish-vegetable greenhouse production system. This system takes the effluent produced by the fish and delivers nutrient laden water to the plant system (vegetables- in these case tomatoes) from a portion of the culture water. This allows somewhat regular but small volume water releases/exchanges from the tilapia culture tanks which improves the overall water quality in the system and provides a portion of the essential nutrients to the tomatoes which would normally have to be purchased by the culturist. This demonstration system integrates the two production technologies and cuts input costs in both.

DEMONSTRATION METHODOLOGIES

Topography

The location of this facility was located at the North Auburn Fisheries Research Station about 5 miles north of the main campus. We have operated the facility for two years which includes two greenhouses which are dimensionally 30' x 96' (or .132 acres).

Water Source and Water Quality Profile

The water source was supplied from a very low volume well and rainwater collected in a nearby rainwater (watershed) reservoir. Both the well and reservoir water contains low hardness and alkalinity (<10 mg/l). There is also access to city water which can be available for emergency purposes, but was not utilized frequently other than washing down the inside of the greenhouses when needed. Most city water contains chloramines which are not volatile. During an emergency situation, sodium thiosulfate can be used to neutralize the toxic chlorine in the city water before being transferred to the fish culture tanks.

Crop Selection: Tilapia and Tomatoes

Several species of tilapia are cultured commercially, but Nile tilapias are the major culture species worldwide. Tilapia tends to perform well under crowded conditions and poor water quality. In a greenhouse setting, tilapia can be held at a near tropical temperature setting, which they prefer for optimal growth. With the market development and processing advances of tilapia, a rapid expansion of the industry has occurred since the 1980's. The development of hormonal sex-reversed techniques has also added in the breakthrough to allow all male mono-sex populations to be raised to a more uniform, marketable size (Popma and Lovshin, 1995).

Florida and California are the top two fresh tomato producers in the United States. Commercial production occurs in 20 states, while backyard gardens are common in most states. The main increase in consumption is largely due to the increasingly popularity of fresh market tomato use in sandwiches and salads. Tomatoes have also been marketed as a good source of vitamin A, vitamin C, and antioxidants, which have been suggested to prevent against specific cancers (USDA, 2005).

With the emergence of greenhouse tomato production, the U.S. fresh market industry has started to change its shape. Greenhouse tomato production allows producers to grow tomatoes in structures that allow adjustment of climate and soil conditions to benefit or increase their tomato production capabilities. There are many advantages to the production of tomatoes in greenhouses including increased yields per acre, uniform appearance and quality, uniformity in production and allowing farmers to more effectively sustain year-round production, if desired.

System Design and Layout:

Basic components

Two Greenhouses

Purpose: Provide controlled environment for tilapia and tomatoes

Dimensions: 96’ x 30’ each

Two 20 mil Plastic Membrane Lined Wood Frame Tanks

Purpose: Culture units for tilapia production

Dimensions: 88’ x 12’ x 4’ each

Volume: 3696 ft^3/tank @ 3.5’ water depth

Capacity: 27,646 gallons/tank @ 3.5’ water depth

Two Low-Pressure Sweetwater Blowers and Diffusers

1.5 HP each, operated on 120V current

420 feet of Colorite Diffuser Tubing

Manually operated auxiliary generator for power outages

One Universal Grain Burner

Purpose: Heat water for tilapia and air for tomatoes during cold months

Capacity: 200,000 BTU

Fuel: shelled corn and wood pellets

Water Flow Management

Water exchanges will take place on a daily basis depending on water quality in the tilapia tanks and nutrient requirements by the tomatoes. Tomatoes require a maximum of 0.75 gallons of water per plant per day. There were a total of 600 tomatoes in the plant greenhouse. The maximum water requirement was about 500 gallons for the plant greenhouse which was mainly supplied from the tilapia culture water depending on nutrient availability. Both tilapia tanks combined yield 55,292 gallons, which means that if we exchanged only the amount of water required by the tomatoes from the tilapia tanks, there was only a 0.65% water exchange each day. A 0-6% water exchange per day was required to maintain the tilapia culture system. This indicates the need for additional plant houses to balance water/ nutrients available for future growth of other vegetables.

Depending on the tomato plants needs, the tomatoes were watered 3-12 times per day to ensure proper water and nutrient amounts. This was accomplished by using an inexpensive swimming pool pump from the tilapia tanks to the plant greenhouse. To supply water to the tilapia tanks, a 3-inch PVC pipe line running from the header tank that is capable of supplying a minimum of 200 gpm was installed. There was also installed a 4-inch line originating from the reservoir pond that will be capable of supplying the same flow rate at times. These water sources are more than adequate for these small but frequent water exchanges.

Production Management

Feeding

Tilipia were fed to satiation 2-4 times per day depending on their size. They were fed a floating 28-32% protein diet (catfish diet) ranging in size from 1.0-5.0mm. Feeding was done to achieve high feeding efficiency (FCR) by this it is meant that feed was offered at about 90% of satiation demand.

Nutrient Management and pH Control

With the continuous nutrient enrichment of the system water supplied by fish feed, and fish excretion we were able to produce and maintain a bacterial floc for assimilation and digestion of the excess nutrients. The floc, immediately available to the fish is readily consumed. The ammonia removal from the water is also increased similar to a biological waste treatment facility. This allows for a high-yield, low impact and more controllable fish production process. The increased harvest of floc by tilapia and the rate of waste synthesis by bacteria improved the performance of the culture system altogether (Brune *et al*, 2004). Measurements of pH within this type system are typically < 6.0 and it is desirable to be maintained below 6.5 to avoid stress constraints from un-ionized ammonia due to elevated pH and temperature.

Water Quality Monitoring Protocol

The dissolved oxygen (D.O.) was monitored twice per day with the first measurement starting in the early mourning and the second just before dusk. Vigorous circulation was created and dissolved oxygen was maintained above 4.0 mg/l at all times and by the regenerative blowers and diffuser system. The pH will also be measured in the morning and just before sunset to minimize large pH swings in the system. Makeup water was also added daily to replace water loss due to tomato watering and also the evaporation from the large surface area of the tanks. The ammonia (ionized/unionized), nitrite, and nitrate was recorded daily in the beginning. On a weekly basis, the hardness, alkalinity, and chlorides will be monitored to ensure proper production conditions. Every two weeks, salt and micro nutrients (elements) were mixed and added directly to the tomatoes to maintain maximum production.

Tilapia Production

A total of 30,000 tilapia were be stocked annually. This was broken up into 2 month staggered stocking regimes utilizing 25-40g fingerlings with an estimated 950% survival there was a total production of 13,800 lbs produced/tank/year. The estimated grow out time for each individual tilapia cohort was six months to reach 1 pound. This yields a production rate of about 1,150 lbs/tank/month or 288 lbs/tank/week.

The staggered stocking regime allows for a constant supply of market size tilapia (1-1.5 lb.) while not flooding the local market during fall as is typical in outdoor production. The basic plan was be to grade the incoming fingerlings thoroughly before stocking into the tank system. The fish were separated by net dividers (hoppas) and the dividers will be expanded as the tilapia grow to ensure proper tank space. As fish reach a 550-800g market size they were selected (culled) and sold. The final total fish production for this system averages 27,600 lbs/year. Calculated on an annualized production per acre basis this exceeds 400,000 pounds per year with a very low investment threshold.

Tomato Production

Two crops of tomatoes were produced per year. The fall crop was transplanted in August and harvested from early November to early January. The second crop was transplanted in late January and harvested from April to the end of June. Careful management was needed in the successful production of tomatoes. Soil samples and leaf tissue analysis were done every two weeks to ensure appropriate nutrient availability, plant growth and fruit development. There has been an average production of 25,000 lbs of tomatoes produced per year (two seasons) in the plant greenhouse. Harvest of tomatoes during the indicated times were done daily or at least every other day.

The tomatoes were cultivated in trenches filled with 100% cotton gin compost, which has been shown to increase tomato production. There are five trenches 90 ft long x 2 ft wide x 1.5 feet in depth.

Disease Prevention and Control

At temperatures above 18^{o}C and without severe environmental stress, tilapias are rarely affected by disease. Tilapias are more resistant to bacterial, parasitic, and viral diseases than any other commonly cultured fish. Fungal infections have been reported after rough handling especially when water temperatures are below 20^{o}C. Streptococcus innae infections have occurred periodically but primarily in recirculating and intensive flow-through systems following handling. Columnaris is likely the most common bacterial pathogen for tilapia cultured in the southeastern U.S. It normally only reaches epizootic levels with excessively high temperatures and environmental or water quality declines. When a disease outbreak does occur, typically the entire tank (system) is treated. (Popma and Lovshin, 1995).

The fungal disease Pithium spp*.* is most commonly associated with tomato seedlings. The temperature ranges for the best development for some fungal species are above 30^{o} C or higher. The best control is to avoid excess moisture and watering, treat periodically with a broad spectrum fungicide, and also avoids contact of fruit to the soil which prevents fruit rot and to use chemical or heat sterilized planting medium (Jones *et al*, 1991). A dilute bleach solution can be effective in a spray in areas of the plant house which tens to develop excess moisture and fungus

Marketing

All tilapia were sold live to both local live haulers and into the local Auburn Fisheries Market by student workers. Demand for live fish is strong and growing so marketing tilapia produced has never been a problem

Tomatoes, a highly perishable crop, were harvested daily or every other day, size graded and boxed. They were sold at the Auburn University fish market and to two local wholesale buyers.

Field Days

Field days have been planned and executed several time over the course of the project. Visitors to the Auburn University E.W. Shell fisheries experiment station are given informal tours of this system on a regular basis, while a more formal and focused target audience attend a scheduled field day. The target audience includes but is not limited to: 1.) Alabama Department of Economic and Community Affairs (ADECA), 2.) Alabama Department of Agriculture and Industries, 3.) Alabama Cooperative Extension Service, 4.) ALFA, 5.) Auburn University Faculty, Students and Staff, 6.) Lee County, 7.) Alabama Nurserymen's Association, 8.) Alabama Fisheries Association, 9.) Alabama Section of ASAE, and 10.) K-12 Students (Chappell).

RESULTS

We demonstrated use of shelled corn as a locally available, economical fuel which cost less than most other fuels. Typical corn pricing at $2.50-3.00 per bushel allowed very economical heating. The corn burning furnace we used was a 200,000 BTU unit which provided hot water in daylight hours to the fish system and hot air into the plant house during the night. Shelled yellow corn holds about 7500 BTU per pound so at the E.W. Shell Fisheries Experiment Station just north of the main Auburn University campus we used about 5-6 bushels per 24 hour cycle to heat the two houses. We conducted a several weeks duration trial (Jan. - Feb. 2008) using wood pellets for fuel as an alternative to corn since corn is currently very high priced. Strategically, purchasing corn in July or August or better yet growing your own would be a better hedge.

System yields were higher than we had projected. The fish system allows production of 10-12 tons of Tilapia per annual cycle. This equates to 350-400,000 pounds per acre per year. Tomato production was similarly robust at about 10,000 pounds per cycle. Two cycles per year would normally be cultured so about 10-12 tons per greenhouse of this size per year. This computes to 300-360,000 pounds of tomatoes per acre per year.

Cost of production for Tilapia is approximately 75-80 cents per pound given current feed pricing but would reduce on a fully commercial system using multiple production houses. Live wholesale price for Tilapia currently ranges from $1.65-2.00 per pound. Tomato production costs were in line with typical greenhouse systems but off-season marketing was able to receive an excellent price at $1.25-1.70 per pound.

The investment threshold for this type enterprise in Alabama is low and is attractive to a broad range of interested farmers.

CONCLUSION

The technology is very simple, requires very little expensive equipment or facilities and thus holds a low enterprise entrance threshold. It is broadly open to many rural Alabamians. It's been seen by more than 750 individuals at mid-year 2008.

The budget analysis displays the profitability of operating a small aquaculture facility/tomato greenhouse system. Some of the fixed and variable costs must be determined on real cost figures associated with a particular locale and real farm but the results of this demonstration are quite positive.

REFERENCES

1. Bailey, D. S., J. E. Rakocy, W. M. Cole and K. A. Shultz. 2006. Update on Tilapia and Vegetable Production in the UVI Aquaponic System. Pre-Publication Draft. Personal Communication.
2. Brune, D. E., G. Schwartz, A. G. Eversole and T. E. Schwedler. 2004. Partitioned Aquaculture Systems. Southern Regional Aquaculture Systems. Publication No. 4500.
3. Chappell, J. A., Personal Communication. 2006.
4. FAO. Livestock, Dairy, & Poultry Outlook. 2006. Economic Research Service, USDA. Available at: www.fao.org/fijis/servlet/firefservlet?ds=species&fid=3217.
5. Jolly, C. M. and H. A. Clonts. 1993. Economics of Aquaculture. Food Products. Press, New York.

6. Jones, J. B., J. P. Jones, R. E. Stall and T. A. Zitter. 1991. Compendium of Tomato Diseases. American Phyto-pathological Society, St. Paul, MN.
7. Lutz, C. G., W. B. Richardson and J. L. Bagent.1998. Greenhouse Tilapia Production in Louisiana. Louisiana State University Agriculture Center. Publication No. 2705.
8. Popma, T. and M. Masser. 1999. Tilapia Life History and Biology. Southern Regional Aquaculture Center. Publication No. 283.
9. Popma, T.J. and L. L. Lovshin. 1995. Worldwide Prospects for Commercial Production of Tilapia. International Center for Aquaculture and Aquatic Environments. Department of Fisheries and Allied Aquaculture. Auburn University.
10. Rakocy, J. E. 1989. Tank Culture of Tilapia. Southern Regional Aquaculture Center. Publication No. 282.
11. Rakocy, J. E., T. M. Losordo and M. P. Masser. 1992. Recirculating Aquaculture Tank Production Systems. Southern Regional Aquaculture Center. Publication No. 454. United States Department of Agriculture, Economic Research Services. Briefing Room.
12. Tomatoes: Trade. January 2005. Available at: www.ers.usda.gov/Briefing/Tomatoes/trade.htm
13. University of the Virgin Islands (UVI) Web site. 2005. Aquaponics: An integrated fish culture and vegetable hydroponics production system. http://rps.uvi.edu/AES/Aquaculture/aquaponics.html