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Tank Culture of Tilapia

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The popularity of live tilapia in the marketplace has driven much of the development of the tank-based industry in the United States. In the southern region, indoor tank culture of tilapia allows year-round production and can be a good alternative to pond or cage culture.

Intensive tank culture offers several advantages over the use of ponds. The high density of fish in tanks disrupts breeding behavior and allows male and female tilapia to be grown together. If cultured together, females will be half the size of the males (0.75 lbs vs. 1.5 lbs; 340 grams vs. 680 grams). Females will not reach marketable size at the same time as the males unless there is a market for the smaller fish. In ponds, mixed-sex populations breed so prolifically that parents and offspring compete for food, individual fish growth is reduced, and the population becomes stunted.

Using tanks allows the fish culturist to manage stocks and have a good deal of control over environmental parameters (e.g., water temperature, dissolved oxygen concentration, pH, waste) that can be adjusted to promote maximum production. In addition, feeding and harvesting operations require less time and labor than in ponds. In small tanks it is practical and economical to treat diseases with therapeutants applied to the culture water. Intensive tank culture can produce high yields, year-round, on small parcels of land.

Tank culture also has disadvantages. Because fish have little natural food in tanks, they must be fed a complete diet containing the protein, vitamins and minerals necessary for good growth. Finishing (often referred to as on-growing) feed for tank culture operations generally has more protein than that used for pond culture, usually 32 to 40 percent protein. Pond culture operations, and those tank operations that are heterotrophic or "biofloc" systems, usually can achieve satisfactory growth rates using feed with lower protein content because fish receive a portion of their nutrition from the pond biota or from the ingestion of bacteria. Biofloc systems maintain an active suspension of bacteria and algae in the culture tanks. These bacteria and algae control the ammonia-nitrogen concentration, while the cells are kept in a constant state of rapid growth and regeneration.

In tank culture, the cost of pumping water and aeration or oxygenation increases unit production costs. The filtration technology of recirculating systems can be complex and capital intensive, and these systems require close attention. The high densities required for profitability also create a vulnerability to disaster if power outages or equipment failure occur. Any tank culture system that relies on continuous water pumping, aeration or oxygenation is at risk of mechanical or electrical failure and major fish mortality without the proper backup systems. Automated alarms, oxygen storage, backup generators and quick response can be critical in saving a crop of fish. Confining fish in tanks at high densities can create stressful conditions and increase the risk of disease outbreaks, especially when water quality deteriorates.

Suitability of tilapia for tank culture

Tilapia have a number of characteristics that make them attractive for tank culture. They can tolerate the crowding and handling that is required in a tank-based facility. Their heavy slime coat protects them from abrasion and bacterial infections that would adversely affect many other fish. Tilapia grow well at high densities in the confinement of tanks when good water quality is maintained, but they are also amazingly tolerant of poor or variable water quality. Tilapia can be grown on diets that are high in vegetable matter, such as soy protein, which is a more renewable and sustainable ingredient than fish meal derived from wild fish catches.

The simplicity of breeding tilapia means that fingerlings can be readily available year-round. This characteristic is important to indoor facilities that produce fish steadily for the live

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market and its customers, which can then rely upon a constant, predictable supply. Fillet yield of most tilapias is 30 to 35 percent of the whole body weight, so 65 to 70 percent of the processed fish is discarded if it is not sold as a live or whole product. Therefore, the more profitable product is the whole/live form.

Species selection

A number of tilapia species have been cultured in the U.S. With the growth of the tilapia industry and stocks moving from state to state, there has been considerable mixing of strains. Among the reasons for selective breeding, genetic selection, and examination of hybrids has been the improvement of growth rate, cold tolerance and fillet yield, and more desirable color variations for the marketplace. The most popular species currently cultured are the Nile tilapia (*Oreochromis niloticus*) and the blue tilapia (*Oreochromis aureus*). However, other species such as the Mozambique tilapia (*Oreochromis mossambicus*) and several hybrids are also cultured. While *O. niloticus* can survive temperatures as low as about 10 °C (50 °F), *O. aureus* can survive to about 7 °C (45 °F) but has a slower growth rate. Although these temperatures may be the lethal limits, water temperature in the 10 to 16 °C (50 to 60 °F) range can stress tilapia, reduce their feeding behavior, and make them more vulnerable to disease.

Tilapias' tolerance of lower temperature may make it possible to overwinter stock in some areas of the U.S., but cold tolerance can be viewed as a negative characteristic by state agencies worried about the survival of escaped fish. As with any aquaculture specie, it is prudent for the prospective aquaculturist to consult regulatory agencies early in the planning process.

Types of culture systems

The successful tank culture of any fish specie is highly dependent upon maintaining good water quality. This is accomplished by aeration, oxygenation, and frequent or continuous water exchange to renew dissolved oxygen (DO) content and remove waste products. Culture systems that discard water after use are called flow-through systems, while those that filter and recycle water are called recirculating aquaculture systems (RAS), recycling or water re-use systems. Each type has advantages and disadvantages.

Flow-through tank systems

Flow-through tank systems depend on constant or periodic water exchange to flush out fish waste products. Exchange rates are determined by the available water quality and quantity, the fish biomass, and feeding rates. As a rule, the volume of water needed for a facility is the amount required to replace 100 percent of the tank water every 90 to 120 minutes.

Flow-through systems often are not suitable for commercial tilapia tank culture. Tilapia are warmwater fish that grow best when the water temperature is in the low to mid-80 °F range (approximately 27 to 29 °C). Unless incoming water is from a geothermal source or is warmed, it will be too cool for optimum growth. Warming large volumes of incoming water is generally not economically feasible. Operations with a constant source of heated water, such as a geothermal or low-cost waste heat source, might be economically viable.

Using surface waters for tank culture is not advisable, although there may be exceptions. The quantity of surface water available may vary during a drought, and its quality can vary because of rainfall runoff, agricultural activity or other development activity in the watershed area. Groundwater is a better source, but it is advisable to gather as much history as possible on the water quality of a site before developing the culture operation. Water from shallow wells may contain organic matter and unacceptable levels of ammonia or hydrogen sulfide gas. Geothermal water sources may have levels of dissolved minerals that affect fish health. It might be possible to treat groundwater before using it, though the operator would need to determine whether treatment is economically feasible.

Water discharged from flow-through tank systems may pollute receiving waters with nutrients and organic matter. Under the regulatory structure of the U.S. National Pollutant Discharge Elimination System (NPDES), the discharge of effluent water may require a permit, with required periodic testing and oversight, based on the following two criteria: 1) annual production must total at least 100,000 pounds (45,400 kg) of product, and 2) discharge of effluent water must occur for more than 30 days annually. These are federal rules, but states are allowed to determine whether one or both conditions must be met before requiring a permit.

Large facilities that exceed the production level of the first criterion should try to use the effluent for crop irrigation or treat it on site and not discharge it off site for more than 30 days of the year. A permit may also be required, at the discretion of the state regulatory agency involved, if any complaint is received. It is prudent, therefore, for the prospective aquaculturist to know the rules of the controlling regulatory agency during the early stages of facility planning and design.

Recirculating aquaculture systems (RAS)

Recirculating aquaculture systems, despite earlier failures, have become more common and more economically viable because of advancements that accomplish the required unit processes: solids removal, biological nitrification, oxygenation, and dissolved gas management. Recirculating systems must be designed to accomplish these processes with less new water input in an economically sustainable manner. Sand filters have largely been replaced by better types of solids removal devices such as bead filters and screen filters. Granular plastic media (bead) filters have undergone extensive development and improvement and are readily available from commercial suppliers. Screen filters that use rotating drums or discs are also widely used. These filters remove solids well, lose very little energy as water passes through them, and discharge very little water during the cleaning process.

Recirculating systems for tilapia culture have a number of advantages. They can be located in areas that do not have sufficient water resources for pond aquaculture. They can be located closer to markets and infrastructure, such as highway connections and utilities. Indoor operations protect the fish stock from seasonal variations in temperature, allowing year-round production that satisfies constant market demand. Depending upon the manager's adherence to good operating procedures and the quality of incoming stock, isolating recirculating tanks from each other promotes biosecurity by controlling the introduction and spread of diseases or parasitic organisms. In some states it is easier to obtain tilapia culture permits for indoor, recirculating systems because there is less chance that these non-native fish will escape.

There are also disadvantages to recirculating aquaculture systems. Probably the greatest problem is the large capital investment required for building and starting up facilities. The need for specialized equipment and thermally efficient buildings significantly raises the cost of getting into the business. Economic analyses for the southern region have shown that the minimum production required for proper cash flow is about 200,000 to 250,000 pounds of live weight tilapia annually. The cost of constructing and starting up a facility with this capacity can exceed $750,000. If funds must be borrowed, a large debt to equity ratio may not be economically viable.

More detailed information about recommendations for the design and operation of recirculating aquaculture systems can be found in SRAC publications 450-459, available at: *http://srac.tamu.edu/*.

Culture tank design

Tanks for culturing tilapia can be of different sizes and shapes as long as they allow for the effective removal of waste solids. Tilapias produce a solid waste that is well-suited for removal from culture tanks. When fed commercial fish feeds, they produce fecal strings held together in a mucous membrane that maintains the feces in a relatively large, filterable size. The longer these solids remain in the tank, the smaller they become (as they disintegrate) and the more waste ammonia they generate, so tanks should be designed for the rapid and efficient removal of waste solids. All manner of tank shapes have been used for culturing tilapia, including square, rectangular, round, oval, octagonal and "D-ended" or "racetrack" configurations. The most desirable tanks are those that effectively remove solids at an affordable cost while using valuable floor space efficiently.

Round or octagonal tanks have a circular flow pattern that moves settleable solids toward a central drain, which is usually screened to prevent fish escape. In tanks with an internal standpipe, the center drain can be fitted with a larger outer pipe (sleeve) with notches at the bottom to remove water from the bottom of the tank where solids are concentrated. External standpipes are easily adjusted to accommodate increased water flows during the culture cycle, while maintaining the same water level in the tank. Tank drains must have screens, slots or some type of open area to prevent clogging that might cause the tank to overflow. Double drains, which create an effluent flow stream with greater solids concentration, perform well and are widely recommended.

If tilapia fecal material is not quickly removed from the tank, the mucous membrane will trap gases generated by bacterial decay and cause the fecal string to float. For this reason, some tanks have an additional surface drain at the center (standpipe) or on the tank sidewall to remove surface water and floating solids.

Research has shown that round or octagonal tanks with flat bottoms have better solids removal than those with sloped or cone-shaped bottoms. The slope may prevent solids from moving to the center drain. Tanks with flat bottoms also are simpler and less costly to build.

System design

System design should be approached in a reverse manner. The final desired fish size and total weight of the harvest is determined, a maximum fish density is established, and assumptions about mortality rate are applied to arrive at initial stocking numbers. Maximum density dictates the maximum daily feed rate, which is usually 1.0 to 1.5 percent of the biomass for market-size fish of 1.5 pounds (680 grams) each. This biomass density (lbs/gal or kg/m^3) is a design parameter that is highly dependent upon the type and size of filtration technology used. Efficient solids filtration makes it possible to use higher feed rates and still keep the system operating within safe limits of dissolved oxygen, dissolved ammonia, pH and suspended solids.

Systems that rely solely on aeration, without supplemental pure oxygen gas, are limited to lower maximum biomass densities unless solids removal is highly efficient and the suspended solids concentration is low. The general rule of thumb is that highly aerated systems in which fish are fed for good growth have a maximum biomass density of about 0.25 pound per gallon(30 kg/m^3), although some operators report achieving maximum fish densities of 0.5 to 0.6 pound per gallon (60 to 72 kg/m^3). Vigorous aeration is necessary to dissolve enough oxygen in the water, especially in the warm water used for tilapia culture. But vigorous aeration re-suspends and fractures solids that should be quickly removed from the tank in order to maintain good water quality conditions. In systems where supplemental oxygen is applied and vigorous aeration is not used, maximum fish density can often exceed 0.50 pound per gallon (60 kg/m^3), and some system designs routinely use a maximum of 0.75 to 1.0 pound per gallon (90 to 120 kg/m^3). For commercial operations, the expense of supplemental oxygen can often be offset by the significant increase in maximum biomass density.

The key to a well-designed system is the efficient removal of solids, because this makes it easier to control other water quality parameters. When waste solids do not remain in the tank and break down into increasingly finer particles, there is less dissolved ammonia and carbon dioxide and a lower oxygen demand. With lower carbon dioxide concentrations, the pH of the system water is more easily maintained for proper biofilter performance.

Tank stocking and density

The tank culture of tilapia can have higher labor and energy costs for pumping water and heating water than pond culture methods. As a result, the most efficient strategy for operating tanks is to keep the biomass at or near the maximum system carrying capacity and maximize feed input, while minimizing the costs of labor and energy. The maximum carrying capacity of a tank should allow for maximum feed conversion efficiency throughout the production cycle. While it is certainly possible to grow fish using a "put and take" scheme—harvesting larger fish and replacing them with smaller fish—this type of stock management can be problematic in a number of ways. The larger fish of a mixed population will compete with smaller fish for feed. Different size fish within a population may require different size feeds. Sorting and harvesting larger fish can be labor intensive and stressful on the fish in the tank. And, it is nearly impossible to distinguish genetic runts from other small fish in the mixed cohort population. Genetic runts do not have potential for good growth and should be identified and removed as early in the production cycle as possible.

The opposite extreme of tank management—stocking fry or fingerlings as a batch directly into the final growout tank—is usually not recommended. A large tank requires a large pump and filtration equipment, which is an inefficient use of resources for such a small initial biomass. The alternative is to use a phased approach, initially stocking fry or fingerlings into smaller, more manageable nursery tanks with smaller volumes of water and smaller pumps and filtration components, and then growing the population until maximum tank capacity is reached. During that phase of growth, average fish size and overall tank biomass increase. As fish biomass and total daily feed increase, water flow through the tank and filtration system must be increased to provide more aeration and biofiltration. When the maximum flow rate or pumping capacity is reached, the tank is at its maximum carrying capacity and the fish are moved to a tank or tanks with greater volume and a filtration system of greater capacity.

This phased approach improves biosecurity, disease control and feed management throughout the growout process. Newly introduced cohorts of fry or fingerlings can be isolated from other populations within the facility to help prevent or control the introduction and spread of disease. As a growout history is developed with a cohort of fish, that cohort can be moved into other areas of the facility with greater confidence that they are healthy. The phased growout strategy also improves population data collection. Fish can be sampled during the transfer process to verify their numbers; determine average weight, growth rate and feed conversion ratio (FCR); and more accurately adjust feed rates for the upcoming phase. Fish transfers are opportunities to grade the fish and split the population according to average size.

Tilapia breeding and fry production

Breeding tilapia is a relatively simple procedure. Regularly producing large numbers of high-quality fry, however, requires greater attention, good broodstock, high-quality feeds, and proper disease controls. While mating can occur and fry can be produced from ratios of one or two females per male, commercial hatcheries usually use four or five females per male. Using a high ratio of females to males is acceptable if the males are superior, since they will theoretically pass their genes on to many fry. These fry, however, should be used only for growout and not for further selective breeding.

Tilapia are commonly bred in tanks. Brood fish are stocked at a rate of 0.06 to 0.14 pound of brood fish per square foot (0.29 to 0.68 kg/m^2) of tank bottom. They produce approximately 0.14 to 0.23 fry per square foot (1.5 to 2.5/m^2) per day. Within 10 to 15 days after stocking brood fish, newly hatched fry can be captured with a dip net and transferred to a nursery unit. Fry that avoid capture prey on subsequent spawns and reduce production. After 1 to 2 months, the tank must be drained to remove all juvenile fish and begin another spawning cycle. Breeding can be better controlled when net enclosures (hapas) are floated in tanks. Male and female brood fish, which have been kept apart, are stocked into the hapa to begin breeding. A sex ratio of two females to one male is used to produce large quantities of fry. The optimum stocking density ranges from 0.5 to 1.0 fish per square foot (5.4 to 10.8/m^2). Small brood fish (0.25 lb, 115 grams) make handling easier, although larger brood fish may be used. The brood fish are fed high-quality feed at a rate of 2.0 percent of their body weight per day.

The most efficient method when hapas are used is to collect eggs at 5-day intervals and incubate them in hatching jars. Eggs are collected by passing a 4-inch PVC pipe float underneath the netting material from one end of the hapa to the other end to concentrate the brood fish in one end. The brood fish are captured individually with two small scoop nets—a large-mesh inner net and a fine-mesh outer net. The nets are held in one hand while the fish is held with the other hand, which is gloved to prevent injury from the dorsal fin. Using a finger to open the fish's mouth, the fish is moved quickly up and down in the water with the nets underneath to wash out any eggs the fish may be incubating in its mouth. Occasionally, a fish will expel its eggs as it is being captured. With a double-net scoop net system, the eggs fall through the large mesh net and are retained by the small mesh net. The large mesh net prevents the fish from crushing the eggs. After each fish is inspected, it can be returned to the other end of the hapa. This method produces approximately one fry per square foot (10.8/m^2) per day.

Monosex culture

The culture of nearly all-male populations is being conducted with good success. All-male populations have better growth rates than mixed-sex populations because there are few slower-growing females, which convert some feed into egg production. There are two methods for producing all-male tilapia fingerling batches: 1) sex reversal of fry using a synthetic male androgen (17-alpha methyltestosterone) administered in feed for 28 days post-hatch; and 2) spawning female tilapia with tilapia males that have two Y chromosomes. A third method, using interspecific hybridization of female *Oreochromis niloticus* and male *Oreochromis aureus*, has been described in the scientific literature and is sometimes used in countries where chemical sex reversal is prohibited. It is not widely used in commercial production in the U.S.

The sex reversal of fry can be conducted only by special permit from the federal government. The use of breeding males with two Y chromosomes is a patented method; broodstock is available to licensees from the patent holder.

Feeds and feeding

One of the characteristics that make tilapias suitable for simple hatchery production is that new fry do not need specialized live feeds such as *Artemia*, rotifers or microalgae. They can be given commercial dry feeds, size 00 or 0, after they have absorbed their yolk sacs. The fine powder form allows some of the feed to float, encouraging surface feeding. Fry this size may eat as much as 20 percent of their body weight (biomass) per day.

At this stage, fry can be given special feed to reverse their sex. This special feed, which must be prescribed by and produced under the direction of a veterinarian, contains a small concentration of male androgen. For up to 28 days post-hatch, this feed is offered to the quickly growing and sexually undifferentiated fry. Properly administered, this feed produces populations of more than 90 percent male fish.

As the fry and fingerlings grow, progressively larger feeds should be offered. The strategy in choosing and changing feed sizes should follow the goal of always offering the largest size feed that the smallest fish of the population can consume. If feed is too large for the smaller members of the population, their feed intake will be reduced, their growth rate will decline, and there will be a greater size difference within the tank population. And by offering the largest size feed that the fish can consume, individual fish will expend less energy in the feeding process.

In their natural environments, tilapias are detritus feeders. They feed by "grazing," and for longer periods than predator fish that pursue and capture prey. Therefore, it is possible to use an extended feeding regime for tank-cultured tilapia, feeding a daily ration over a period of 10 to 12 hours or longer. Some researchers have reported that better feed conversion will result if tilapia are not fed continuously, but are given a rest period, during which their metabolism decreases. The method of feeding used, by hand or by automatic feeder, determines whether a feeding schedule can be extended. Each method has advantages and disadvantages. Feeding manually over longer periods of time increases labor cost but allows feeding to be monitored. Using mechanized feeders makes it easier to schedule feed delivery to individual tanks throughout a daily cycle.

In both flow-through and water reuse systems, extending the feeding schedule over a longer period also spreads out the impact of feed on water quality parameters. Feed can be delivered to the system at more even intervals to moderate the high and low variations of these parameters. When oxygenation is used, there is less need to adjust oxygen input to maintain optimum dissolved oxygen levels. When dissolved oxygen concentrations are low, feed conversion ratios can be affected; when dissolved oxygen concentrations are high (supersaturation), oxygen is being wasted.

With hand feeding, an operator can observe feeding behavior and reduce or increase feed depending upon the reaction of the fish. Feed can also be spread over the tank surface to allow more fish to feed. Should fish concentrate and feed in one area, feed can be applied in a different area to attract those fish that were crowded out. Trained feed applicators can also become skilled at identifying changes in water quality from the feeding behavior of the fish. As feeding slows, feed application can be decreased or stopped to reduce the amount of uneaten feed.

Tank-cultured tilapia can have very efficient feed conversion ratios (FCR). The time period for FCR can be days, weeks, the length of the tank production cycle, or a year. FCRs in the range of 1.4:1 to 1.8:1 are common with tilapia and are some of the best in animal agriculture. While FCR is one of the most important benchmarks for measuring the efficiency of an operation, FCR alone does not give a true measure of production. An artificially low FCR can be created by underfeeding, so it is important to consider the growth rate also.

The cost of feed is a large part of an operating budget so it must be used wisely. Table 1 contains guidelines for feed sizes and feeding rates for tank culture of tilapia.

Table 1. Suggested feed size and feeding of tank-cultured tilapia.

Average weight (grams)	Standard feed size	Range of feeding rate (% biomass/day)
Post-hatch – 0.5	#00, #0, #1 Crumble	20 – 15
0.5 – 5	#2 Crumble	15 – 10
5 – 18	#3 Crumble	10 – 5
18 – 75	#4 Crumble (1 mm)	5 – 3
75 – 150	$^{1}/_{8}$ inch (3 mm)	3 – 1.5
150 to market	$^{3}/_{16}$ inch (5 mm)	3 – 1.5

To achieve projected weekly weight gains, the corresponding total amount of feed must be fed and consumed by the fish population during that week. In systems that are not properly designed for good solids removal, biofiltration, dissolved gas stripping, and aeration or oxygenation, poor water quality often occurs before the required daily ration is fed. This is especially true near the end of the growing period when biomass is nearing maximum. When this occurs, the manager can 1) reduce or suspend feeding or 2) begin water exchanges.

To ensure that targeted growth rates are achieved for a given week, the manager will estimate the beginning and ending biomass of the tank based upon estimated growth rates, assume a realistic FCR, and calculate the total amount of feed required for that week. For example, if a growth rate of 5.0 grams per day per fish is expected and the tank contains 10,000 fish, a total of 350,000 grams (350 kg) of weight should be gained for the week. Assuming an FCR of 1.7:1, the manager would need to feed 595 kg of feed for the week (1.7 x 350 kg = 595 kg). The daily feed rate would have to average at least 85 kg (595 kg ÷ 7 days/week = 85 kg). If that feed rate cannot be reached, the manager should look for an explanation so the problem can be remedied. Often poor water quality is the cause of the problem. The fish may not be eating aggressively due to the stresses of high ammonia levels, nitrite toxicity, low dissolved oxygen, high levels of carbon dioxide, or other water quality problems.

Water quality requirements

Tilapia are some of the hardiest fish being cultured; they can withstand water quality conditions and physical handling that would create serious challenges for other species. However, tank culturists need equipment that analyzes the minimum basic water quality parameters of dissolved oxygen, temperature, pH, ammonia, nitrite, alkalinity, chloride concentration, and calcium hardness. The equipment should be of good enough quality to allow daily measurements, so that daily readings can be compared to determine the effect of increased feed and fish biomass on water quality from one day to the next.

Strict water quality parameters for tilapia culture are difficult to define. Experience at one site may not reflect the same results as those reported in a scientific publication or from another system at another location. There are variables that influence the effect a particular parameter, such as ammonia concentration, has on various fish. Water quality variables interact in complex and often poorly understood ways. Variables such as water temperature, pH, hardness, general fish health, feeding history, and sound and light stressors all have a role in determining whether the lethal level of a particular parameter has been reached.

The following water quality guidelines are based on published information as well as the authors' experience in the tank culture of tilapia. For further information, the following texts are recommended:

C. Lim and C.D Webster (eds). 2006. *Tilapia—Biology, Culture, and Nutrition.* New York: The Haworth Press.

M.B. Timmons and J.M. Ebeling (eds). 2007. *Recirculating Aquaculture.* NRAC Publication No. 01-007. Ithaca, New York: Cayuga Aqua Ventures.

Temperature — Optimum growth for tilapia is achieved at 81 to 84 °F (27 to 29 °C), but acceptable growth rates are reported at 77 to 90 °F (25 to 32 °C). Temperatures in the extreme upper range make it more difficult to maintain dissolved oxygen concentration.

Dissolved oxygen — Operating levels of between 5.0 and 7.5 milligrams per liter (mg/L) are recommended. Growth and feed conversion will be affected by chronically low DO concentrations below 3.5 mg/L. Survival and recovery are possible with short-term exposure (less than 10 minutes) to DO concentrations as low as 0.8 mg/L.

pH — Tilapia can survive a wide range of pH, from 5 to 10, but are said to grow best at pH 6 to 9. In tank systems, dissolved carbon dioxide causes pH to decline because of the formation of carbonic acid (H_2CO_3) in solution. Low pH is not as serious a problem in flow-through systems as in water reuse systems, in which a minimum pH of 6.8 is suggested as the lower limit of tolerance for the nitrifying bacteria of the biofilter. Due to the presence of dissolved carbon dioxide, high pH is generally not a problem in tank systems. (See also Carbon dioxide.)

Ammonia (NH_3) — Ammonia exists in two forms in the tank environment, un-ionized NH_3 (highly toxic) and ionized NH_4^+ (less toxic). Avoid concentrations of un-ionized ammonia greater than 1.0 mg/L. Consult other sources to understand the relationship between pH and the toxicity of Total Ammonia Nitrogen (TAN), un-ionized ammonia and ionized ammonia.

Nitrite (NO_2^-) — Avoid concentrations greater than 5 mg/L nitrite-nitrogen if chloride (Cl^-) is low (less than 10 mg/L). Add rock salt to maintain chloride concentration of 150 to 200 mg/L under normal operating conditions, and increase chloride concentration when nitrite is elevated. The chloride ion alleviates nitrite toxicity and can be added as sodium chloride (NaCl) or calcium chloride ($CaCl_2$).

Nitrate (NO_3^-) — Nitrate toxicity can occur if levels in water reuse systems exceed the 300 to 400 mg/L nitrate-nitrogen range. Normal water exchanges during filter backwashing or solids removal generally control nitrate concentrations. Water exchange or a denitrification process may be required.

Carbon dioxide (CO_2) — Maintain at less than 40 mg/L. Elevated carbon dioxide levels cause lethargic behavior or slow feeding response in fish. While tilapia can tolerate a wide range of pH, dissolved carbon dioxide gas stripping is required in water reuse systems to keep pH above 6.8 and promote conditions favorable to nitrifying bacteria in the biofilter.

Calcium hardness — Maintain between 50 and 100 mg/L. Dissolved calcium in the water aids in osmoregulation and relieves stress in fish. It is usually added as calcium chloride ($CaCl_2$), which dissolves readily and also increases chloride (Cl^-).

Chloride (Cl^-) — Maintain between 100 and 300 mg/L. See description under Nitrite. Also see the Harvesting and Marketing section.

Alkalinity — This is the measure of the pH buffering capacity of water, and should be maintained at 100 to 250 mg/L by adding a soluble carbonate or bicarbonate source. Sodium bicarbonate is commonly used because it is readily available, highly soluble, and safe to handle. Dissolved carbon dioxide reduces pH, so higher alkalinities must be maintained if CO_2 stripping is poor. Choosing a water source with higher alkalinity reduces operating expenses because less supplemental alkalinity will be needed.

Further water quality guidelines for recirculating aquaculture systems can be found in SRAC publication 452, *Recirculating Aquaculture Tank Production Systems: Management of Recirculating Systems.*

Harvesting and marketing

In the southern U.S., tank culture of tilapia is carried out primarily for the live fish market. The harvesting of tilapia requires a certain amount of preparation and special handling. The generally accepted size for the live tilapia market is approximately 1.5 pounds (680 g), although fish weighing as little 0.75 pound (340 g) and as much as 2.0 pounds (908 g) will find acceptance in some areas. As the average weight of the stock in a tank approaches market size, buyers, harvest crews and live haul transporters should be coordinated.

Tilapia are usually prepared for sale by purging them, or withholding feed for a period before harvest and transporting. This allows the fish to rid their digestive systems of wastes and improves conditions in the hauling tanks during transport to market. Purging time varies and is influenced by water quality conditions, the type of feed and its ingredients, and the preferences of the marketplace. Withholding feed for 3 to 5 days before harvesting and marketing is common. During that time, water should be exchanged to improve water quality and reduce temperature. Lowering the temperature to about 72 °F (22 °C) slows the activity and the metabolism of the fish and increases the dissolved oxygen in the hauling tanks. Fish grown in recirculating systems often develop off-flavor, which is thought to be caused by the fish feed or bacterial content of the culture system. Purging helps reduce off-flavor problems and may cause the fish to begin utilizing fat reserves where the compounds that cause off-flavor may be concentrated.

Rock salt or non-iodized salt should be added to the hauling tank to help alleviate stressful conditions. Food grade salt that contains the anti-caking agent yellow prussiate of soda (sodium ferrocyanide) should not be used, because this cyanide-based compound is toxic to fish. Although it is not currently approved for food fish, rock salt is classified as Low Regulatory Priority (LRP) by the U.S. Food and Drug Administration. Dissolving salt in the transport water brings the salt concentration of the hauling water up to the salt concentration of the fish's blood. Rates of about 6.5 pounds of salt per 100 gallons of water are recommended. This equates to a salinity of about 7.8 parts per thousand (ppt). With appropriate preparation, live tilapia can be transported by truck for 18 hours or more with little mortality, and can be held for live sale for up to 1 week after harvest.

Proper handling of fish during the harvesting stage enhances survival and ensures that strong fish will be available to the buyer in the event that fish must be held in a live facility before sale. Tanks should be drained to a water depth that is comfortable and safe for harvesters. A depth of about 50 inches (127 cm) is workable if fish are not so crowded that they jump excessively and risk injury to themselves or workers. Close attention should be paid during the draining and crowding process so that dissolved oxygen levels of 4.0 mg/L or greater are maintained. Stressing fish and causing mortality at this stage risks the resources that have been invested in the operation. Minimizing the number of times the fish are handled between the time they are captured in the culture tank and released into the live haul tank will significantly improve their survival when they reach the fish dealer's facility. Scooping the fish in the same basket in which they are weighed and carried to the live haul tank reduces handling and the abrasion and removal of the fish's slime coat.

Harvesters should wear protective eyewear or face shields, gloves, and chest waders or long pants to protect themselves from injury.

All parties involved—the fish producer, the live hauler and the fish dealer—should regard the live fish as a sensitive item, worthy of great care and proper handling, so that all are rewarded with the reputation of producing and delivering a high-quality product.

Conclusion

Much has been learned about the tank culture of tilapia since the early days of production. Successes and failures have added to our knowledge of system design, species selection, stock management and nutrition. There are a number of recurring short courses, workshops and conferences where prospective tank aquaculturists can learn to plan, design, build and operate facilities with confidence. Before putting significant capital at risk, it is to your advantage to use these resources, along with resources available on the Web and from your state Cooperative Extension Service.

SRAC fact sheets are reviewed annually by the Publications, Videos and Computer Software Steering Committee. Fact sheets are revised as new knowledge becomes available. Fact sheets that have not been revised are considered to reflect the current state of knowledge.

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