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Aquaculture Water Quality for Small-Scale Producers

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1. Introduction

Today we known that solar energy can be stored as edible biomass by photosynthesis, but 10,000 years ago this assumption was unthinkable. However, the Neolithic man could developed agriculture, based on plant germination observations. Nowadays, the systems used for food production are practically the same (Koning et al., 2008). But for neolitican man, the empirical observation of germination processes and biological cycles of certain species ended in the discovery of agriculture.

Even our agriculture is still the same, the climate scenario is changing. Our current carbon-based economy has caused massive greenhouse emissions, and consequences are global warming and the depletion of the ozone layer. The biological, economical and social impact on the environment is significant. Water scarcity and natural catastrophes (tsunamis, earthquakes, floods and erosion) damage cultivable land, reducing local food availability (Franck et al., 2011, IPCC, 2007).

Clearly, it is necessary the innovation of new food production systems. Aquatic food production is an alternative to land-based, 2-dimensional systems (Alagaraja, 2007). Due to physical differences between air and water (thermal conductivity, heat capacity, density, etc), most aquatic organisms do not use energy in thermal regulation. The consequence is a more efficient food-tissue conversion ratio compared with land-based system yield (FAO, 2010).

There are limitations, of course. Because overfishing causes fish stock depletion, aquaculture has become an alternative to provide fish products (Naylor, 2009; Brander, 2007; Pillay et al., 2003; Naylor, 2000).

The notorious growth in aquaculture has been possible by the application of science. Aquacultural and fisheries science produce new and replicable knowledge based on scientific method. The research is usually done in farms or in a laboratory. The mathematical and analytical methods used by researches are generally robust and provided a verifiable knowledge. Nevertheless, there is a gap between the scientific results and its practical use. Lukefar (1999) pointed out that the examples taught on classroom lectures are usually based under realistic, idealized situations. But there is a necessity to find practical solutions applicable for commercial aquaculture.

The problem of the academic extension is an important issue in aquaculture if we consider that small-scale aquaculture provides almost half of the worldwide inland fish production (FAO, 2010). Kawarazuka (2010) commented "aquaculture and small-scale fisheries can improve the food intake". Mohanty et al. (2010) mentioned that at least 90 % of the people involved in aquacultural practices works in small fisheries.

Facing the problem of the continuous rising world population, it seems to be clear that the good use of all natural resources (including small freshwater bodies), must be done. So there is an important, unattended practical knowledge field to be considered. Technologies for small-scale fish producers are ready available (Van Gorder, 2003), and the current knowledge on aquatic science can be helpful for the producer with the goal to optimize its own resources (time, land, water and energy).

The objective of the present chapter is to present selected topics on water quality management, especially if they can be carried out by low-cost technologies in small systems. Due to the close relationship among water quality and yields, we hope it can be helpful as a practical guide for fish producers based on scientific principles.

2. Overview of water quality in aquaculture

Water is the physical environment where fish develop, growth and reproduce. The dynamic of the mass and energy involved on an aquaculture system is complex, because bacteria, algae and fish growth together in the pond (Wheaton, 1982). The main energy input comes from sunlight, and nutrients of the system are commonly provided by pelletized fish feed. So the transformation of the elements carried out by autotrophic and heterotrophic organisms change the physical/chemical/biological composition of the water (Hargreaves, 1998).

Temperature and pH are fundamental for the aquatic living organisms, due to the intimate relationship between them and the velocity of its biochemical processes. Oxygen (O_2) and carbon dioxide (CO_2) are important molecules because they are involved in photosynthesis and respiration processes. Nutrients like nitrogen are essential on biological metabolism: when is ingested as protein or amino acid, it can be incorporated by the organism as functional proteins or in structural tissues. But when is excreted by the fish as ammonium (NH_3), in certain circumstances it can be toxic and even lethal in high doses. Another nutrients, like phosphorus, potassium and calcium are also important, and they lack are usually diagnosed by deficiency.

Besides the physical and chemical factors, the biotic component also can change the water composition. For example, algae can consume of produce oxygen and carbon dioxide, depending on light presence or absence. The nitrogen, phosphorus and potassium can be used and assimilated by unicellular organism, incorporating them as biomolecules. Moreover, the nitrogen can be also used to produce energy on chemoautotrophic biochemical cycles (Hargreaves, 1998).

So, the biological impacts of water quality over the cultivated species could be analyzed under physical, chemical or biological perspectives. For practical purposes, a quick overview of the basic principles is given below. The parameters mentioned have been divided into two main categories: Critical and important parameters.

2.1 Critical water quality parameters

The critical parameters are very important in the aquacultural system. They are temperature, pH, dissolved oxygen (DO) and ammonia. They must be measure daily, or in the case of intensive systems, all day long. They do influence the physical properties and chemical composition of the water, and thereafter its correct management can improve the overall fish performance (health and growth). In the other hand, if they are not properly attended, the consequences can be serious, varying from poor growth rates, stress, and death.

2.1.1 Temperature

Temperature is probably the most important physical variable on aquatic ecology. It affects directly the metabolism of all living organisms. As a consequence, temperature set the growth, development and reproduction rates in biological species in biological species. This fact is very useful in aquaculture: because fish do not expend energy on corporal temperature regulation, they can assimilate almost the food nutrients into muscular tissue (Soto-Zarazúa et al., 2011). As results of an adequate temperature condition, the biomass production and final yield of the fish farm can increase.

It is important to remark the influence of temperature in fish respiration rate. A rise of temperature causes more oxygen consumption in bacteria, algae and fish (Boyd, 1998). Because respiration implies carbon dioxide release and energy consumption, the gas balance can be dangerous for fish. If there are enough inorganic nutrients in the water, the algae biomass can increase to considerable levels. Even some algae species can double its biomass in only 3.5 hours (Brennan & Owende, 2010). Then, the elevated rates of nutrient assimilation will produce significant impacts on the water quality.

In other hand, a higher temperature produces higher metabolic rates. The increment in fish metabolism enhances the protein breakdown. As a consequence, the release of NH_3 by fish will be high, too. The resulting combination of high temperatures with NH_3 high concentration is very a toxic environment (Eshchar et al., 2006).

Finally, if the exposure to high temperatures is very long, the structure of the proteins begins to break, causing fish death.

2.1.2 pH

The pH is a measure of acidity and basicity inside an aqueous solution. It indicates the concentration of hydrogen ions on water. When pH is below 7 the solution is considered acid, and when is above 7 is named basic or alkaline. Distilled water has a pH of 7. pH can be defined as the negative logarithm of the molar concentration of hydrogen ions on water. In mathematical notation, pH is described as

$$pH = \log\frac{1}{[H^+]} = -\log[H^+]$$

Where [H^+] is the concentration of hydrogen ions. Fish and other vertebrates have a pH blood value near to 7.4. The contact between environmental water and fish blood is only separated by one or two cells of the gills. An ideal pH for an aquacultural system must be near to 7. The lethal limits are below 5 and above 10, for most of the fish species.

There is an important relation between fish respiration and pH. In the gills the gaseous interchange of O_2 instead CO_2 occurs. This interchange can be difficult if pH is not optimum. The effects are called Bohr and root. So even if we have enough oxygen in our system, if pH is not adequate fish could not breathe (Wurts & Durborow, 1992).

pH, like temperature, is always changing. For example: In afternoon, the oxygen concentration decrease and the phytoplankton photosynthesis stops by the absence of sunlight. The concentrations of O_2 and CO_2 began to change, and the pH can vary due its intimate relationship with CO_2 equilibrium (Wurts & Durborow, 1992). Another important factor to take into account is that cinematic of certain types of bacteria can change in low pH, so the mass and energy transformations of the pool carried out by unicellular organism can influence the environment (Ebeling et al., 2006).

2.1.3 Dissolved oxygen

According to Rumei et al. (2003), dissolved oxygen is the most important manageable variable in aquaculture. The oxygen is necessary to glucose breakdown and energy release inside fish cells. However, its diffusivity and availability on water is mediated by temperature, elevation and salinity (Boyd, 1998).

Low concentrations of oxygen can produce negative impacts on fish health, like poor growth performance, low feeding rate, and increase risk on potential diseases or even fish death. These impacts are specific for every fish species. The particular oxygen requirements depend principally on the fish biology. For example, trout needs a high quantity of oxygen (about 7 ppm), but catfish (bottom, detritivore fish) can survive with only 0.5 ppm of oxygen (Akinwole & Faturoti, 2007).

The presence of dissolved oxygen on aquaculture water ponds depends on physical factors (salinity, temperature and altitude), algae photosynthesis or artificial supplying (Boyd, 1998). Oxygen consumption depends on the carry capacity of the systems. The fish biomass is an important factor to be considered in a system, because the food supplied to the fish plays an important role in water ponds biogeochemistry (Timmons, 2002; Hargreaves, 1998).

2.1.4 Ammonia

The ammonia is a nitrogen compound excreted by fish through gills and faeces. So the amount of ammonia is in direct relation with the amount of feed input on the pond. Ammonia can also be produced in pond by organic material decomposition driven by bacterial activity (Durborow et al., 1997a).

The ammonia is presented in two forms: the high toxic un-ionized ammonia (NH_3), and the non-toxic ionized ammonia (NH_4^+). They are in chemical equilibrium driven by temperature and pH. The sum of NH_3 and NH_4^+ is called Total Nitrogen Ammonia (TAN). In general, the fraction of toxic ammonia increases at elevated temperature and high values of pH (Durborow et al., 1997a), as it can be seen in the following equation:

$$\frac{NH_3}{TAN} = \frac{K_{eq}}{10^{-pH} + K_{eq}}$$

Where k_{eq} is the negative logarithm of pK ($pK = -\log(K_{eq})$), and $pK = 0.09018 + 2727.9 - (T + 273.1) + (0.1552 + 0.0003142T)I$, T is temperature (°C) and I is Ionic strength (M) (Eshchar et al., 2006). For more convenient purposes, computations of ammonia toxic fractions can be made with the tables provided by Durborow et al. (1997a). Measures of TAN, pH and temperature are required.

2.2 Important water quality parameters

The dynamic of the important parameters occurs slower than the reactions implicit on critical ones, so they can be monitored with less frequency. Solids, nitrite (NO_2), nitrate (NO_3), carbon dioxide (CO_2), hardness and alkalinity can be measure once a week. Lethal effects on the fish at high concentrations of this parameters are not common, but their accumulation can affects directly and indirectly the fish growth. Also, if unfavourable conditions are presented, an enhanced risk to infections or diseases can be presented.

2.2.1 Solids

In aquaculture, the solids are placed into a special category because in most of the cases they can be controlled by good management practices. Solids in pond are presented as uneaten food, faeces, fish scales, dead bacteria and algae, dust, and dead fish (Cripps and Bergheim, 2000). The adverse consequences driven by the presence of organic solids in the system are caused mainly by bacterial processes. It implies additional oxygen consumption and carbon dioxide release, among other effects. In some anoxic environments, hydrogen sulfide (H_2S) and ammonia can be release to water by bacterial bacterial anaerobic processes.

In general, the solids can be classified in three major divisions. 1) Settleable solids, wich can be easy separated by sedimentation or decantation (for example, uneaten feed, fish scales, faeces); 2) Suspended solids, which are very fine solids without the capacity of rapid sedimentation (about 1-10 μm on diameter); and 3) dissolved solids, which are nano-scale elementary forms as molecules or atoms. (Losordo et al., 1999; Malone, 1991).

In general, the impacts of the solids in aquaculture systems are negative. For example, in the surface when the water turbidity rises, the photosynthetic activity in algae decreases. In bottom, accumulation of solid wastes causes anaerobic zones, in which undesirable bacteria can proliferate. In ponds, high clay turbidity usually causes acidity, low nutrient levels, and limited light penetration for photosynthesis (Yi et al., 2003). Dead fish are solids too, and its presence on culture water can be a factor for pathogenic propagation inside the farms (Cripps & Bergheim, 2000).

Is useful to think that solids on aquacultural environments are mainly composed by organic material. If they remain in the water, they became basics nutrients, like nitrogen and phosphorus that could be easy assimilated by microscopic organism. So the total oxygen budget will rise (Timmons et al., 2002).

2.2.2 Nitrite

The presence of nitrite inside an aquaculture pond is often caused by ammonia biological oxidation (Hargreaves, 1998). The stoichiometric reaction is the following:

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + 2H^+ + H_2O$$

As a result, there is a free energy yield (ΔG) of – 65 kcal mole^{-1} from the ammonia oxidation.

This reaction is carried out by bacteria that naturally growths in the aquacultural environment. Bacteria of the genus *Nitrosomonas* are the main responsible for nitrification in aquaculture, but there are other important genus involved in this processes (Hovaneck & DeLong, 1996; Ebeling et al., 2006).

The physiological effects of nitrite in the fish health are mainly caused by a chemical reaction on the haemoglobin. The role of this protein is the oxygen transportation all over the blood stream. In the presence of nitrite, haemoglobin becomes methaemoglobin, a non-efficient oxygen transporter (Jensen, 2003). As a result of oxygen deficit, the fish blood became brown, and a gasping behaviour can be observed. If nitrite intoxication remains unattended, massive fish dead became after a short time caused by hypoxia (Masser et al., 1999).

High nitrogen concentrations in ponds occurs more frequently in the fall and spring, when low and fluctuating temperatures cause decay rates on phytoplankton and bacteria metabolisms (Durborow et al., 1997b).

2.2.3 Nitrate

The presence of nitrate in aquaculture water is water is delivered as a waste product of organic bacterial activity in the pond. The reaction involves the presence of nitrite and oxygen. The following stoichiometric reaction shows the overall process (Wheaton, 1982).

$$NO_2^- + 1.5O_2 \rightarrow NO_3^-$$

In total, when a nitrite molecule is oxidized, a free energy yield (ΔG) of -18 kcal mole^{-1} is released. In aquacultural ponds, the most representative bacteria genus that can perform the nitrite conversion to nitrate is *Nitrobacter*, but other genus of bacteria are commonly presented during the nitrification (Camargo et al., 2005).

The nitrate is commonly controlled in aquaculture systems by dilution. In intensive recirculation systems between 5 and 10% of water are removed and replaced every day. In systems with low technification, the daily water exchange usually is more than 10%.

A natural pathway to remove the nitrite in an aquacultural system is done by denitrification. The reaction is carried out by bacteria in absence of oxygen and in presence of methanol as a carbon compounds. The general reaction is done in two steps (Van Rijn et al., 2006):

$$NO_3 + \frac{5}{6}CH_3OH \rightarrow \frac{1}{2}N_2 + \frac{5}{6}CO_2 + \frac{2}{3}H_2O + OH^-$$

2.2.4 Carbon dioxide

Carbon dioxide (CO_2) in aquatic systems is very important, because its presence is required in some chemical and biological processes. For example, CO_2 interacts with water to form a natural buffer system which helps to maintain a constant pH. Is also important for biological primary production, because is necessary in algal photosynthesis to synthetize glucose. Is important to note that biological activity can also release CO_2 to the media, when fish and algae breathe. Some bacteria also need CO_2 to maintain its metabolic cycles in constant function.

Bacteria also release CO_2, both autotrophs and heterotrophs. For example: The free acid produced during nitrification reacts with bicarbonate alkalinity in water to release more CO_2 than autotrophs consume. So for every gram of TAN metabolized, 4.6 ppm of oxygen will be consumed, and 5.9 g of CO_2 will be released. In heterotrophic reactions, for every gram of O_2 consumed, 1.38 g of CO_2 is released (Summerfelt & Sharrer, 2004).

When CO_2 is dissolved in water, part of it combines to form carbonic acid (H_2CO_3). This weak acid tend to react with calcium carbonate ($CaCO_3$) to form calcium bicarbonate [$Ca(HCO_3)$], which is often dissociated on hydrogen ions and carbonate ions (Wheaton, 1982):

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3 \leftrightarrow H^+ + HCO_3^{2-}$$

These four reactions are mediated by hydrogen concentration. They proceed to the right when pH rises and they go to the left when pH decreases. Therefore, the carbon dioxide usually can be found in water under four different forms: As free gas (CO_2), as carbonic acid (H_2CO_3), as carbonate (CO_3^{2-}) and as bicarbonate (HCO_3^-) (Wheaton, 1982). Thus, the chemical importance of CO_2 relies in the fact that is a pH buffer, and it has a lot of relation with other physicochemical parameters, like hardness and alkalinity.

2.2.5 Hardness

The hardness is defined as the total concentration of calcium and magnesium ions, expressed as calcium carbonated. However, if other metallic ions are presented in the water (Al, Fe, Mg, Sr, Zn) they can be also considered in the definition (Wheaton, 1982).

The hardness is an important water quality parameter because a direct relation between water metal content and pH variations exists. When the concentration of Ca and Mg trends to be higher, the buffering capacity of the water becomes higher, too, and is more capable to smooth pH variations. In other words, hard water is more stable than soft water.

In the biological perspective, calcium is important in fish metabolism, because is used on the scale and bond formation, and to keep the adequate balance of Na and K in the blood (Wurst & Durborow, 1992). Calcium is often required in neural synapses, and in physiological ion balance. In the case of magnesium, it is used is used by photosynthetic organism because is embedded in the center of the chlorophyll molecule, and it is also required as prosthetic group in proteins (Müller-Esterl, 2008)

In the farm, hardness is very important when the organisms are cultivated for reproduction purposes in hatcheries. If invertebrates are cultivated, hardness becomes an important variable to consider, because Ca and Mg are very important in the formation of hard parts (i.e., exoskeleton or shells).

Changes in the water hardness are slowly. They take place typically in weeks or months.

However, is a good management practice to monitoring this variable constantly.

2.2.6 Alkalinity

The alkalinity is the amount of acids (H^+) that water can neutralize before to reach a given pH. It is defined as the stoichiometric sum of the bases in a solution. Common bases found in fish ponds include carbonates, bicarbonates, hydroxides, phosphates and berates. Carbonates and bicarbonates are the most common and the most important components of alkalinity. Because total alkalinity can be expressed as ppm of $CaCO_3$, is common to confuse it with hardness (Wurts & Durborow, 1992).

Like another water quality parameters, alkalinity can be affected by the biological activity of systems. Because photosynthesis of phytoplankton requires CO_2 to synthesize glucose, pH in the water increases due to inorganic carbon adsorption in water (mainly H_2CO_3 and CO_3^{2-}). During long periods of intensive photosynthesis, the release of carbonate can elevate the pH levels over 9. These effects can be observed if water has low alkalinity (20 to 50 ppm) or low bicarbonate (75 to 200 ppm). High photosynthetic activity can be presented when the sodium and potassium carbonates are dissolved in water, because they are more soluble than calcium and magnesium bicarbonates (Wurts & Durborow, 1992).

3. Low-tech water quality management

Currently, the aquacultural engineering gives a considerable number of solutions to control the variables involved in aquaculture water quality. In general, they are available commercial devices and chemical products to control water quality. However, there are alternative techniques used by scientist that considered the pool as a bioreactor. New aquaculture techniques are bio-flocs (Avnimelech, 2006), Integrated Multi-trophic Aquaculture (IMTA) (Chopin, 2003), greenwater systems (Hargreaves, 2006), Zero-Exchange water systems (Panjaitan, 2010; Olvera-Olvera et al., 2009) and aquaponics (Rakocy & Hargreaves, 1993), among others.

3.1 Temperature

The temperature control on aquaculture could be difficult, because the high specific heat capacity of water (4.18 $kJ\ kg^{-1}\ °K^{-1}$) implies a high amount of energy when water is heated or cooled. In addition, the water volume used on aquacultural facilities is frequently high, so the monetary and environmental cost to raise water temperature could be unaffordable (Seginer & Mozes, 2008).

There are several alternatives to increase thermal stability on aquaculture. The most effective system is the use of greenhouse to cover aquaculture ponds or tanks (Soto-Zarazúa et al, 2011; Fuller, 2007). Some farms use heating pumps, thermosolar systems, fossil fuel heaters or electric resistances, but all of them are expensive ways to heat water, both by initial and operational cost. Besides, some of them imply negative environmental impacts caused by greenhouse gas emissions (Mohanty et al., 2010).

Nevertheless, there are alternatives for the small-scale producers. The most effective strategy is a good planning on farm building. Then, the most important thing is to pick a good geographical location. The climate and the temperature of the make-up water must be adequate for the cultivated fish. An analysis of the local climatologically data, if available, can give us an idea if the selected location is proper to our intentions.

If low air temperatures are presented, covering the tanks with plastic sheets could be is useful (Van Gorder, 2003; Crab, 2009). On the other hand, if temperature rises, a packed aeration column can be built as a chiller (Wheaton, 1982). In both cases (low and high water temperatures), to add new make-up water can be useful. Is also important to remember that some fish doesn't growth on winter, like tilapia (Crab et al., 2009)

If fish tanks are used, it could be helpful to cover its walls with heat insulators. Elastomeric foams are a good choice, because they are generally designed to support extreme insulation and hard management. Fiber glass and polystyrene foams could be used, too (Alatorre, 2010).

Another option is to consider solar heating water systems. Despite the high initial cost, they can help to raise the water temperature from 1 to 5 °C. Solar pool blankets, geodesic structures and active/passive solar collectors have been tested with considerable results (Fuller, 2007). A practical guide and cases studies is available in www.retscreen.net. A complete guide to thermosolar processes can be found on Duffie and Beckman (1992).

3.2 pH

A common action to pH control is the addition of chemical substances. When pH is low, it could be useful adding lime (Wurts and Durborow, 1992). If pH rises, small amounts of phosphoric acid or acetic acid can help to neutralize water. Some people uses sulphuric acid, but it can be dangerous if there is no previous experience on dangerous substances management. Another way to pH control is the enrichment of the biological activity in the pool (Hargreaves, 2006).

In our experience, many traditional aquaculture managers do not monitoring pH. This can be a bad choice, because as we discussed previously, a certain combination of temperature, pH and ammonium can kill entire production stocks.

In the case of aquaponics systems, pH management is fundamental. In this kind of systems plants, fish and bacteria are cultivated. In general, the nitrogen cycle is completed inside the culture water, and the final metabolite (nitrate) is assimilated by plants. As a result, the nutrients provided by fish feed are recycled, and the negative environment impacts are diminished (Diver, 2006). But there is a problem. The optimum pH value for plants, fish and bacteria is 6, 7 and 8 respectively. There is necessary reconciling pH in this systems. Tyson (2008a,b) recommended a pH value of 8 to improve nitrogen assimilation by bacteria.

3.3 Dissolved oxygen

Mechanical aeration is by far the most common and effective way to increasing DO concentrations in ponds. In semi-intensive aquaculture, aeration is applied in case of emergency.(Boyd, 1998).

Paddlewheel aerators and propeller-aspirator-pumps are the most common aerators used in aquaculture. Aeration amounts varies from 1-2 kW ha^{-1} in extensive cultures, to 15-20 kW ha^{-1} in intensive culture of marine shrimp. For every kW of aeration extra, the gains are estimated over 500 kg fish/crustacean biomass (Boyd, 1998).

All basic types of mechanical aerators have been used in aquaculture, but vertical pumps, pump sprayers, propeller-aspirator-pumps, paddle wheels, and diffused-air systems are the most common. However, paddle wheels aerators and propeller-aspirator-pumps are the most efficient devices (Boyd, 1998).

There are some useful indications about the use of aerators. In semi-intensive culture, is common to turn on mechanical aeration at night, when is a lack of photosynthesis and the respiration rate is in a maximum value. However, is important to note that if the aerators are operated on sunny afternoons when water is supersaturated, oxygen will be lost (degassed) from the water (Tucker, 2005)

When commercial aerators are not available, a degassing column can be constructed with local available materials. Wheaton (1982) mentioned how to build a simple aeration tower. Tucker (2005) gives photos and a short description about it uses on farm systems. Theoretical background can be found in Boyd (1998), Summerfelt et al. (2000) and Vinatea & Carvalho (2007)

3.4 Nitrogen compounds

Ebeling et al. (2006) pointed out the following: for every gram of ammonia-nitrogen converted to nitrate-nitrogen, 4.18 of dissolved oxygen and 7.05 g of alkalinity (1.69 g of inorganic carbon) are consumed and 0.20 g of microbial biomass (0.105 g organic carbon) and 5.85 g of CO_2 (1.59 g inorganic carbon) are produced. So the nitrogen cycle in pond water affects the physical, chemical and biological components present in the system. To control the accumulation of every kind of components in the pond the most usual method is the addition of make-up water. However, there are alternatives to manage the levels of nitrogen compounds. Some of them are described below.

3.4.1 Ammonia

The most extended method to control ammonia inside aquacultural ponds is to keep a good feeding schedule based on nutrimental tables. If the feeding regimen in the fish farm is intensive, then pH control is also recomended. If pH can be maintained lower than 8, the toxic fraction of TAN will remain in minimal percentage (Hargreaves and Tucker, 2004).

A common method to control ammonia in recirculating aquaculture systems is a biofilter addition in the system. Biofilters design and theoretical foundations are already in literature (Bazil (2006), Drennan II et al. (2006), Eding et al. (2006), Gutierrez-Wing and Malone (2006), Kuo-Feng & Kuo-Ling (2004)). Examples of applications and affordable designs can be found in Soto-Zarazúa et al. (2010), Timmons et al. (2006), Al-Hafedh et al. (2003) and Ridha & Cruz (2001)

Another method to control ammonia is the increment of microbiological activity inside the pond (Hargreaves and Tucker, 2004). The addition of organic carbon in relation with nitrogen concentration is very useful (Crab et al., 2009). Theoretical background of this technique (also named bio-floc technology) is already available in Avnimelech (2006, 2003 and 1999).

3.4.2 Nitrite

A common practice to reduce nitrite toxicity is the elevation of chloride concentration in the culture water (Losordo et al., 1998). For this purpose, common salt (sodium chloride) is used. Calcium chloride can also be used. A high chloride:nitrate ratio of 10:1 is used to prevent brown blood disease. In catfish, for example, is recommended to maintain at least 100 ppm chloride in pond waters (Durborow et al., 1997).

When brown gill disease is not presented, a good practice is to flush water. In general, the absorption of NO_2 by bacteria is presented in tanks and ponds. To enhance its activity, biofiltration is recommended.

3.4.3 Nitrate

In general, nitrate is a non-toxic form of nitrogen in pond. However, nitrate management is usually carried out by water exchanges. Phytoplankton and bacterial uptake is another method to assimilate nitrate into cellular tissue (Gross et al., 2000). Aquaponics is another way to assimilate NO_3 into fresh, marketable plant biomass, as lettuce, tomato, basil and other crops (Graber & Junge, 2009; Rico-García et al., 2009; Savidov et al., 2005).

Denitrification is also an alternative to eliminate aquacultural nitrate. Theory and practice examples can be found in van Rijn et al., 2006.

3.5 Solids

The management of solids include feed design and management, flow regulation and separation treatment technology (Cripps and Bergheim, 2000). In small scale aquaculture, a good start point is to asses an adequate feed schedule. In our experience, we have noted that overfeeding is usual in new managers, so the detriment of the water quality is faster.

Fish also waste a lot of feed. In the case of tilapia, even 50% of their feed can be wasted (Avnimelech, 2003). So the experience of the manager is fundamental in solids control.

A complementary approach to treat solid wastes is a quickest remotion of them (Timmons et al., 1998). In general, the settleable solids can be easily remove from the culture water. If circular tanks are used, the centrifugal forces and conical bottoms must help to accumulate the solids in the center drain. (Timmons et al., 1998; Summerfelt et al., 1998). If rectangular tanks are used, is recommended to adjust length/width ratios to increased bottom velocities and reduced biosolid accumulation (Oca and Masaló, 2007). In some cases additional components can be used, like settling basins or hydroclones (Wheaton, 1982). For aquaponics, the size reduction of solid wastes from pellets to fine particles or even until basic organic compounds is desirable (Rakocy & Hargreaves, 1993).

If extensive ponds are used, the use of chemicals to enhance flocculation of organic particulate material could be useful. The addition of gypsum helps to diminish the negative electrical charges between particulate material, enhancing the flocculation and sedimentation of suspended solids. The recommended amounts are between 100 to 300 mg per liter (Hargreaves, 1999).

3.6 Carbon dioxide (CO_2)

In general terms, rarely CO_2 concentration cause problems in fish ponds with sufficient alkalinity. However, if the pond is deeper than 5 feet and poor mixing is presented, there is a risk of water stratification (Hargreaves and Brunson, 1996). Vigorous aeration can prevent stratification, and it would be helpful if CO_2 is saturated on pond water (Wurts and Durborow, 1992).

Other alternative is chemical treatment. The addition of quicklime, hydrated lime or sodium carbonate will increase the alkalinity of the pond, dropping the presence of dissolved CO_2 in water. Treatment calculations can be found on Hargreaves and Brunson, (1996). In the case of intensive systems, CO_2 could be a problem. In this case, the addition of a degassing tower is recommended (Summerfelt and Sharrer, 2004).

4. Conclusions

The processes involved in aquaculture water quality are affected by many variables and they are generally complex. However, the driving forces involved in fish farms can be controlled in order to increase fish productivity. This control involves learned skills to make the right decisions to correct present problems and to prevent new ones.

In this chapter we had discussed extensively the theoretical foundations of fish water quality, with emphasis on small-scale aquaculture correction techniques. As it can be seen, physical, chemical and biological processes involved in the pond dynamics are strongly related, and they can´t be considered as isolated phenomena. The understanding of these processes can be useful to improve the final yields on the farm with the minimal waste of time, energy and money. As a result, the sustainability of the protein production can be rise and the negative environmental impact can be diminished.

5. References

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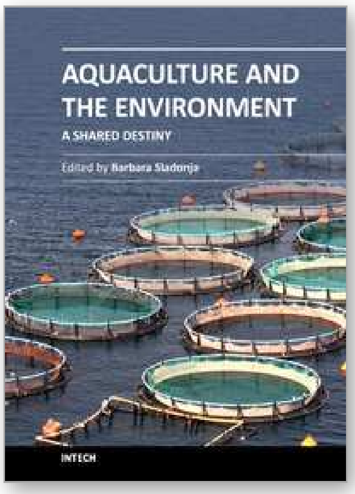

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