Important Water Quality Parameters in Aquaponics Systems

Circular 680
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Introduction

Aquaponics, a method of food production that combines fish farming with soilless plant production, is growing in popularity and gaining attention as an important and more sustainable method of growing food. Aquaponics combines the cultivation of both fish and plants into a recirculating ecosystem that utilizes natural nitrifying bacteria to convert fish wastes into plant nutrients. For more basic information on aquaponics, refer to NMSU Extension Guide H-170, *Is Aquaponics Right For You?* (http://aces.nmsu.edu/pubs/_h/H170.pdf).

Because this system combines plants with animal production, it has a special set of water chemistry requirements, and optimal water quality is essential to a healthy, balanced, functioning system. This guide describes the most important water quality parameters that affect the health and productivity of aquaponics systems. A good understanding of how these parameters interact with each other is necessary in order to maintain a balanced system. For additional information on water chemistry, refer to NMSU Extension Guide W-104, *Understanding Water Quality Parameters to Better Manage Your Pond* (http://aces.nmsu.edu/pubs/_w/W104.pdf).

Source Water

Selecting the source of water used in an aquaponics system can greatly influence the water quality, and is an important first consideration. Potential sources include well water, municipal water, and surface water. Surface water is not recommended because of the difficulty in ensuring consistency in water quality due to risk of contamination. Municipal water is treated with chlorine and chloramines, which must be removed before it can be used. Whatever source of water is used, it is very important to have it tested and to obtain a water quality profile to ensure that it meets the requirements to grow fish and plants.

Testing Frequency

Testing frequency will vary depending on the parameter being monitored. However, as a general rule, start-up systems should be tested daily so that adjustments can be made quickly when needed. For example, in response to high ammonia levels, feeding levels can be reduced, aeration can be increased, or water can be diluted. Once nutrient cycles are balanced, weekly testing is usually sufficient.

In all cases, it is important to record all of your readings. Keeping good records of your water quality measurements can help greatly in observing trends and diagnosing future problems.

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Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important parameters for growing fish and is also critical to the beneficial nitrifying bacteria that convert fish waste into nutrients plants can use.

Warmwater fish (e.g., bass, bluegill, and catfish) require about 5 ppm (ppm or parts per million, which can be used interchangeably with milligrams per liter [mg/L]) and coldwater fish (e.g., trout) require about 6.5 ppm of DO to maintain good health and maximum growth. Tilapia are tolerant of lower levels of DO, but growth rates will be affected. They will come to the surface for oxygen-rich surface water if DO levels go down to 1 ppm. It is recommended that DO levels be maintained at **5 ppm** or higher in aquaponics systems. Oxygen levels should be measured frequently in a new system, but once procedures become standardized (e.g., proper fish stocking and feeding rates are determined, sufficient aeration is provided) it will not be necessary to measure DO as often.

Low DO levels are not usually a problem with hobby aquaponics growers with low fish stocking rates. The problem tends to arise more in commercial operations with high stocking rates. If DO levels in your system are too low, increase aeration by adding more air stones or switching to a larger pump. There is no risk of adding too much oxygen; when the water becomes saturated, the extra oxygen will simply disperse into the atmosphere. Dissolved oxygen levels are strongly related to temperature: the warmer the water, the less oxygen it can hold.

Ammonia

Ammonia is the first form of nitrogen released when organic matter decays and is the main nitrogenous waste excreted by most fish and freshwater invertebrates. Ammonia is excreted by fish mainly through the gills and also in trace amounts through urine. Ammonia can exist in two forms: un-ionized (NH_3) and ionized (NH_4^+), also known as ammonium ion. Un-ionized ammonia is extremely toxic to fish, and ionized ammonia is not, except at extremely high levels.

The ratio of NH_3 to NH_4^+ in water at any given time will depend on the pH of the water and the temperature. At pH 7.0 or below, most ammonia (>95%) will be in the non-toxic form (NH_4^+). This proportion of non-toxic to toxic ammonia will increase greatly as pH increases. Water temperature will also affect the ratio of NH_3 to NH_4^+, with more toxic NH_3 present at any given pH in warmer water than in cooler water. For example, at 82°F, the percentage of ammonia that is in the toxic form (NH_3) is 2% at pH 7.5, compared to 18% when pH is 8.5. The sum of the gaseous toxic form and the non-toxic ionic form of ammonia is called Total Ammonia Nitrogen (TAN). TAN is what most commercial ammonia test kits measure. It is recommended that TAN in aquaponics systems be maintained at **<1 ppm**. However, fish can tolerate higher TAN levels if the pH of the water is less than 7.0. If you are using a kit that measures TAN and you want to calculate how much of the TAN is made up of the toxic form, you can refer to Table 1.

To determine the concentration of un-ionized (toxic) ammonia (NH_3) in your water at any given time, multiply total ammonia concentration (TAN) measured in the water by the percentage value given in Table 1 that is closest to the observed temperature and pH of your water sample.

Summary of Steps:

Step 1. Use a water kit to measure TAN
Step 2. Measure the water temperature
Step 3. Measure the water pH
Step 4. Find the multiplication factor in Table 1 that is closest to the water temperature and pH that you recorded
Step 5. Multiply the TAN value by the multiplication factor from Table 1

For example, a TAN of 5 ppm at pH 9 and 68°F would be 5 ppm total ammonia × 28.4% = **1.42 ppm of un-ionized ammonia.**

Ammonia Removal and Utilization in Aquaponics Systems: Biofiltration

If the ammonia excreted by fish were allowed to accumulate it would soon kill the fish. In aquaponics systems, however, the ammonia excreted by fish is removed by nitrifying bacteria that transform ammonia into nitrate nitrogen in a two-step process known as nitrification. First, ammonia and ammonium are converted to nitrite (NO_2) by *Nitrosomonas* bacteria. This process requires oxygen, destroys alkalinity, produces acid (H^+), and lowers pH. In the second step, nitrite (NO_2), which is also highly toxic to fish, is converted to nitrate (NO_3) by *Nitrobacter* bacteria. This second step also requires oxygen and lowers pH. The non-toxic nitrate produced in this reaction serves as plant nutrients in the hydroponic component of the aquaponics system.

Nitrification performs optimally when dissolved oxygen levels are high and organic matter (produced by uneaten fish food and other accumulated solid wastes) is low. If oxygen levels are too low, the rate of nitrification will slow down or stop altogether, leading to an accumulation of ammonia to levels that are toxic to the

Table 1. Percentage of Total Ammonia Nitrogen (TAN) in Freshwater that is in the Toxic Un-ionized Ammonia Form at different pH values and temperatures (adapted from data presented in Francis-Floyd et al. [2009] and Florida Department of Environmental Protection Chemistry Laboratory Methods Manual [2001])											
	Temperature										
	50 (°F)	60.8	64.4	68	69.8	71.6	76.1	78.8	82	86	89.6
pH	10 (°C)	16	18	20	21	22	24.5	26	28	30	32
7.0	0.18	0.294	0.342	0.396	0.425	0.457	0.546	0.607	0.697	0.799	0.95
7.2	0.29	0.466	0.540	0.625	0.673	0.723	0.863	0.958	1.10	1.25	1.25
7.4	0.46	0.736	0.854	0.988	1.06	1.14	1.36	1.50	1.73	1.98	2.36
7.6	0.73	1.16	1.35	1.56	1.67	1.80	2.14	2.36	2.72	3.11	3.11
7.8	0.16	1.82	2.12	2.44	2.63	2.80	3.35	3.68	4.24	4.84	4.84
8.0	1.82	2.86	3.31	3.82	4.10	4.39	5.21	5.75	6.56	7.46	8.77
8.2	2.86	4.45	5.16	5.92	6.34	6.79	8.01	8.75	10.0	11.3	13.2
8.4	4.45	6.88	7.93	9.07	9.69	10.3	12.1	13.0	15.0	16.8	19.5
8.6	6.88	10.5	12.0	13.7	14.5	15.5	17.9	19.4	21.8	24.3	27.7
8.8	10.5	15.7	17.8	20.0	21.2	22.5	25.7	27.8	30.7	33.7	37.8
9.0	15.6	22.7	25.6	28.4	29.9	31.5	35.5	37.7	41.2	44.6	49.0
9.2	22.7	31.8	35.2	38.6	40.4	42.1	46.5	49.2	63.8	56.1	70.8
9.4	31.8	42.5	46.3	49.9	51.8	53.5	58.0	60.5	63.8	66.9	70.7
9.6	42.5	53.9	57.7	61.3	63.0	64.6	68.5	70.8	73.6	76.2	85.9
9.8	53.9	65.0	68.4	71.6	72.9	74.3	77.6	79.4	81.6	83.6	85.9
10.0	65.0	74.6	77.4	79.9	81.0	82.1	84.5	85.9	87.5	89.0	90.6

fish. Nitrite is toxic to fish at levels of 5 ppm; for tilapia, nitrite levels should be maintained at or below 1 ppm.

The removal of ammonia and nitrite in aquaponics systems is referred to as **biofiltration** (Figure 1). Biofiltration is the link between the fish component and the hydroponic component of an aquaponics system. Without a healthy and functioning biofilter, waste products produced in the fish production component will accumulate, inadequate amounts of plant nutrients will be produced, and the system will not perform properly.

A biofilter is a place for nitrifying bacteria to colonize. In raft and media-filled bed aquaponics systems, a separate biofilter is sometimes not used because the rafts, media, tank walls, and other surfaces may provide enough area for bacteria to colonize. However, most of the time these systems still use some type of biofilter to help break down organic matter and provide more micronutrients and dissolved CO_2 in the water. In NFT (nutrient film technique) style systems a separate biofilter is definitely needed.

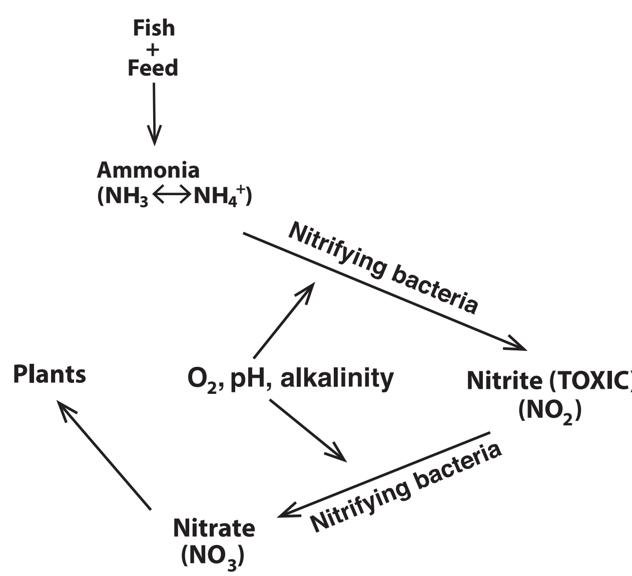

Figure 1. **Schematic representation of the biofiltration process in aquaponics systems.**

The Role of Ammonia in Establishing a Biofilter

The process of building a bacterial colony during the initial setup of an aquaponics system is known as biofilter establishment, or **cycling**. Cycling is the essential first step in setting up any aquaponics system. Until a healthy community of nitrifying bacteria has been established, the cycle is not complete and it will not be possible to grow plants.

Basically, the process involves the steady, constant introduction of a source of ammonia into the aquaponic unit, which feeds the new bacterial colony and allows it to grow, thereby creating a biofilter. There are two ways to establish a biofilter, either with fish in the system or without fish (known as fishless cycling).

Cycling with Fish

Cycling with fish requires 4 to 6 weeks for sufficient bacterial populations to develop. It is strongly recommended to use a low stocking rate of fish and to feed the fish at a very low rate to prevent too much ammonia from building up in the system and killing the fish. Ammonia and nitrite should be measured daily during this process. Ammonia levels will initially increase as levels build up because there are not enough nitrifying bacteria in the system to convert the ammonia produced into nitrite. The increase in ammonia will be followed by a decrease in ammonia levels as *Nitrosomonas* bacteria begin to convert ammonia to nitrite. The drop in ammonia levels will be followed by an increase then a decrease in nitrite levels as *Nitrobacter* bacteria convert the nitrite to nitrate. Once nitrates are detected in the system and the ammonia and nitrite levels have both dropped to 0.5 ppm or lower, the system is fully cycled and ready to grow plants. At this point it is no longer necessary to monitor TAN and nitrite levels on a daily basis.

Nitrite is toxic to fish at 5 ppm, so it is important not to let TAN or nitrite levels exceed 1 ppm during establishment. If levels of nitrite rise above 1 ppm, water should be diluted by performing a water exchange; remove up to a third of your tank's water and replace it with fresh, dechlorinated water, ensuring that the temperature and pH of the replacement water are the same as the water remaining in the tank to avoid further stress to the fish.

Fishless Cycling

Biofilters can also be established without fish by adding ammonia compounds to the system and allowing bacterial colonies to establish in response to these additions. There are two advantages of fishless cycling over cycling using fish. First, there are no worries about accidentally killing fish during the process. This is always a risk when dealing with potential buildups of ammonia. Second, the process takes less time than the fish method (10 days to 3 weeks versus 4 to 6 weeks). This method allows you to control exactly how much ammonia is added to the system, and the amounts can be cut back if needed. Like when you cycle with fish, as soon as ammonia and nitrite levels drop to near zero and measurable levels of nitrate are detected, your system is fully cycled and you are ready to add fish. Once you have added fish, stop adding ammonia because the ammonia produced by the fish will replace the ammonia you have been adding to feed the bacteria.

There are a number of ammonia products available for use in fishless cycling. They include liquid ammonia (also known as clear ammonia, pure ammonia, or pure ammonia hydroxide) and crystallized ammonia in the form of ammonium chloride. **Make sure it is pure ammonia and does not contain any perfumes, soaps, or additives because these are harmful to the system.** Pure ammonia can sometimes be difficult to find. Try your local hardware store, cleaning supply stores, or superstores. Another option is to order it online. There are specialized aquaponics suppliers that sell startup and cycling materials. Ammonium chloride (crystallized ammonia) can be purchased at aquarium supply stores, aquaponics supply stores, soap supply stores, and photography supply stores. In addition to ammonia products, liquid nitrifying bacteria (commercial products such as Microbe-Lift, Cycle, Top Fin, and Stress-Zyme) can be purchased from aquaponics suppliers and most aquarium and pet stores to help speed up cycling.

Making Ammonia and Nitrate Adjustments in Your System

Ammonia Levels Too High

Even after your system is fully cycled, it is a good idea to check ammonia levels on a weekly basis to catch changes early and make adjustments before they become big problems. Higher than desired ammonia levels occur when more ammonia is being produced than can be handled by the biofilters. Possible causes for this include overfeeding of fish, fish densities that are too high for the volume of water (a rule of thumb is 1 lb of fish per 2 gallons of water), or not enough aeration. Pumps and DO levels should be checked, and adjustments in feeding rates or fish density should be made.

Ammonia Levels Too Low
If plants are not growing, it could be because not enough ammonia is being produced in the system. Enough ammonia must be produced and converted to nitrate in order for the plants in your system to grow. Low ammonia occurs when there are not enough fish or there is too much water for the number of plants being grown. The solution is to add more fish to your system, feed them more, or use a smaller tank.

Nitrate Levels Too High
While nitrate is the essential and desirable nutrient byproduct of biofiltration, excessive levels (greater than 150 ppm) could be an indication that not enough plants are being grown in the grow beds to take up all the nitrates that are being produced by the nitrifying bacteria. To address overly high nitrate levels, more plants could be added to the existing grow beds, more fish could be harvested to reduce the amount of ammonia being produced, or another grow bed could be added to the existing aquaponics system.

pH
One of the most important water quality variables in aquaponics systems is pH. The term pH stands for the power of hydrogen, and refers to the concentration of hydrogen ions in a solution. pH can range from 0 to 14, with values between 0 and 7 being acidic, 7 being neutral, and values between 7 and 14 being basic or alkaline. It is considered a "master variable" because it influences many other parameters, such as the ratio of toxic to non-toxic ammonia in aqueous solutions (see Table 1) and the rate of nitrification on biofilters in aquaponics systems. It is important to maintain pH at levels that are acceptable to both fish and plants. Tilapia, for example, require pH to be in the range of 5.0 to 10.0. Plants, on the other hand, grow best when pH levels are below 6.5. Nitrifying bacteria perform optimally at pH levels greater than 7.5 and basically stop working when pH levels fall below 6. The compromise that is optimal to all three components of an aquaponics system—fish, plants, and nitrifying bacteria—is a pH of 6.8 to 7.0. However, maintaining pH within such a narrow window can be difficult and may lead to unnecessary adjusting and tweaking. As long as the pH is maintained between 6.4 and 7.4 it will be tolerable to all three components of the system.

Adjusting pH
It is important to measure pH every day because it normally declines daily in response to nitrification processes. If pH levels get too low, nitrification will slow down or stop and ammonia will accumulate to levels that are toxic to the fish. When pH drops below 6.4, a base in the form of calcium hydroxide or potassium hydroxide should be added to the system to bring it back up to 7.0. Additions of the two bases should be alternated because both calcium (Ca) and potassium (K) are essential nutrients that must be supplemented in aquaponics systems. Here is the Southwest, water is alkaline and high in calcium content, so adding extra water rather than calcium hydroxide is often sufficient to raise the pH. Failing to measure pH for several days can lead to drops in pH to levels as low as 4.5. At pH 4.5, nitrification has stopped and TAN concentrations can climb to over 30 ppm. When this happens, it is crucial to add base very slowly over several days. Adding a large amount of base all at once will shift the majority of the TAN into the toxic un-ionized form (NH_3), and this could kill all the fish.

Occasionally a problem can develop in which the pH does not decline over time but instead remains stable or starts rising. This can be due to something in your system causing pH to rise, such as hard water or other sources of minerals, such as net bags of crushed oyster shells that are sometimes added to systems to stabilize pH and add calcium. Rising or stable pH can also be indicative of anaerobic (oxygen-free) zones in your aquaponics system where denitrification is occurring. Denitrification produces alkalinity and stabilizes pH. To remediate this situation, filter tanks should be cleaned twice a week, and all deposits of organic matter accumulated in the hydroponic section should be removed.

Water Hardness
Water hardness is a measure of positively charged ions, particularly calcium (Ca^{2+}) and magnesium (Mg^{2+}). Total hardness is the sum of the concentration of Ca^{2+} and Mg^{2+}, as expressed in ppm calcium carbonate ($CaCO_3$). Hardness can range from soft (0–75 ppm) to very hard (>300 ppm). Dissolved calcium in the water aids in osmoregulation and relieves stress in fish. Levels should be maintained between 50 and 100 ppm.

Alkalinity
Alkalinity refers to the buffering capacity, namely the ability to resist changes in pH, of a solution. It is a measure of the total concentration of bases in a liquid, and is expressed as the equivalent concentration of calcium carbonate ($CaCO_3$). In aquaponics systems, alkalinity should be maintained at 100 ppm $CaCO_3$ or above.

Water Temperature

Water temperature in aquaponics systems will influence not only what type of fish can be reared but also plant growth and the performance of the biofilter. Fish species are temperature-dependent. Warmwater species such as goldfish, bass, catfish, and tilapia prefer temperatures ranging from 65 to 85°F, while coldwater species such as trout thrive at temperatures in the range of 55 to 65°F. Tilapia prefer temperatures of 81–85°F (27–29°C) for maximum growth. When water temperature drops below 70°F, growth slows dramatically, reproduction stops, and the incidence of disease increases. Tilapia will die when temperatures drop below 50°F. Vegetables grow best at temperatures ranging from 70 to 75°F, and biofilters (nitrifying bacteria) perform optimally at temperatures ranging from 77 to 86°F. As with other water quality parameters, the key is to find a temperature that falls within the acceptable range for all three components of the aquaponics system.

Settleable Solids

Fish solid wastes (feces, uneaten feed, and biological growth) accumulate in fish tanks over a short period of time and are large enough to settle in the tank bottoms. One pound of feed produces 0.25 to 0.30 lb of solids. It is advisable to remove this solid waste from the flow stream through filtering or settling before it enters the biofilters or grow beds. If solids are not removed they will adhere to plant roots, decreasing DO levels as they decay. This will negatively affect the plants' ability to take up water and nutrients. Because these excess solids use up DO as they decompose, they also negatively impact nitrifying bacteria, which require oxygen to convert ammonia and nitrite to nitrate. Thus, as the solids decompose, oxygen will be consumed and ammonia will be produced. In addition to their effect on the water quality of the system, settleable solids will also clog pipes.

Nutrients Required for Plant Growth

Plants require a number of essential macronutrients and micronutrients to grow. Fortunately, most of these nutrients are provided to the plants by the fish feed and by-products produced in the fish component of aquaponics systems (see Table 2). The exceptions are calcium, potassium, and iron, which may need to be supplemented. Calcium and potassium will be supplemented when calcium hydroxide and potassium hydroxide are added to increase pH. It is therefore advisable to alternate additions of these bases to ensure that the system receives adequate amounts of these two macronutrients. Equal amounts of each base, determined by trial and error, should be added as needed to maintain pH at 7.0. Iron should be supplemented by adding 2 mg/L of chelated iron every 3 weeks or as needed. Chelated iron designated as DPTA is recommended.

Table 2. Nutrients Required for Plant Growth (nutrients followed by asterisks are those that typically need to be supplemented in aquaponics systems)

Macronutrients	Micronutrients
N – Nitrogen	Cl – Chorine
K – Potassium**	Fe – Iron**
Ca – Calcium**	Mn – Manganese
Mg – Magnesium	B – Boron
P – Phosphorus	Zn – Zinc
S – Sulfur	Cu – Copper
	Mo – Molybdenum

Table 3. Optimal Water Quality Values for Productive and Well-performing Aquaponics Systems

Aquaponics systems in general	Tilapia aquaponics systems
Temperature: 65–85°F	Temperature: 81–84°F
pH: 6–7	pH: 7
TAN: <1 ppm	TAN: <1 ppm
NO_2: <1 ppm	NO_2: <1 ppm
NO_3: 5–150 ppm	NO_3: 5–150 ppm
DO: >5 ppm	DO: >5 ppm

Summary

Maintaining a balance between water quality conditions that are optimal for fish, nitrifying bacteria, and plants is crucial to a healthy and productive aquaponics system. By monitoring key water quality parameters such as pH, temperature, and TAN on a regular basis, adjustments can be made in a timely manner to avoid problems and losses in productivity. A variety of kits and meters are available to measure these variables. For most backyard systems, aquarium test kits are adequate. Keep in mind that if your readings exceed the higher ranges, you will need to dilute your test sample. Table 3 provides optimal values for the important water quality parameters in aquaponics systems in general (systems containing either warmwater or coldwater fish) and in tilapia aquaponics systems in particular. Of course, this does not mean that aquaponics systems will not function if values deviate from these ideal levels. Tilapia in particular are very resilient fish that can withstand fluctuations in water quality and poor water quality conditions and still survive. These are simply guidelines to inform growers of optimal conditions to help them make better decisions on how to manage a healthy, functioning system.

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