EHT-147 10/20

# WATER QUALITY IN AQUAPONICS

Joe Masabni[1], Todd Sink[2]

Water is the medium through which plants and fish receive their nutrient and oxygen requirements. It is important to understand basic water chemistry to properly manage an aquaponic system, including how to run a profitable and sustainable operation and get the most out of plants, fish, and bacteria.

There are five key water quality parameters for aquaponics: dissolved oxygen (DO), total nitrogen concentrations, pH, hardness, and water temperature. Factors that are equally as important, but not as often attended to by growers are alkalinity, carbon dioxide, settleable solids, and suspended solids. These nine parameters will be discussed in this article.

Knowing the role of each parameter on the health and performance of fish, plants, and bacteria is crucial. However, the optimal values of these parameters differ among fish, plants, and bacteria. Therefore, compromises are made for some water quality parameters to meet the needs of all organisms in an aquaponic system at the same time.

**Table 1. The target ranges for each parameter are as follows:**

| | |
|---|---|
| DO | 5–8 ppm |
| Ammonia | 0 ppm |
| Nitrite | 0 ppm |
| Nitrate | 5–150 ppm |
| pH | 6–7 |
| Water Hardness | 60–140 ppm |
| Water Temperature | 64–86°F |

Modified from: Small-scale aquaponic food production, FAO publication 589.

## WATER TESTING

Water testing is essential to confirm and maintain good water quality in a system. Bacteria cannot be seen or measured directly. Therefore, water testing is the only method of indirectly diagnosing bacteria's health and activity. A grower should design and follow a schedule for water testing. A new grower is encouraged to check water quality parameters daily. During the initial system start-up or the first 2 months, ammonia and nitrite should also be tested daily and then weekly thereafter to monitor the health of bacteria and fish populations. Ammonia and nitrite should also be tested anytime abnormal fish mortality occurs to rule out potential toxicity due to a bacterial population collapse. Once the nutrients have leveled off and the system is considered in balance, measurements can be taken weekly.

## WATER SOURCES

The first step when planning a new aquaponic operation is to determine the quality of available water. If poor water is the only available source, aquaponics will never be profitable. Therefore, it is important to know what your water quality—or more precisely, water chemistry—is first, before you expose fish or plants to it. There are four possible sources of water for use in an aquaponic system: well water, municipal water, rainwater, and reverse osmosis (RO) water. Surface water is not recommended, as it may contain high levels of solids, unwanted fish or insect larvae, aquatic vegetation including algae, and possibly pathogenic microorganisms.

Well water may contain micronutrients like calcium, sodium, or iron, which are beneficial to plants in trace amounts but may also contain compounds that are toxic to fish. Therefore, a water test should be done before use. Well water may be superior to municipal water, which often contains chlorine or chloramine at levels that can be toxic

---

[1] Associate Professor and Extension Vegetable Specialist
[2] Associate Professor and Aquaculture Extension Specialist

to plants or fish. Growers who plan on using municipal water must treat the water to remove excess chlorine or chloramine before adding fish or plants.

Removal of excess chlorine can be done using an RO system or by aerating for a couple of days to allow for the chlorine gas to escape. Chlorine test kits are available at stores selling pool supplies and at many pet supplies stores. Chloramine is more stable and does not evaporate easily. Growers must use a chemical treatment to remove chloramine from the municipal water. Treatments, such as charcoal filtration, or dechlorinating chemicals, such as sodium thiosulfate, are widely available and have proven successful. It is generally suggested to use 3 to 5 parts of sodium thiosulfate to neutralize 1 part of chlorine. Aeration has also been proven to reduce chloramine levels, but it is more difficult with large volumes of water and may take several days. If a grower replaces less than 10 percent of the water at one time using municipal water during normal operation and maintenance of an aquaponic system, the risk from chlorine or chloramine is greatly reduced. However, for the health and safety of the bacteria and fish in the system, it is always recommended to treat water with a chlorine neutralizing agent when adding it to a system.

Rainwater requires a large storage system, and in many areas, rainwater may be in short supply during periods of need while operating a system. Rainwater is free but may not be suitable in areas where acid rain is a common occurrence, such as large cities. Rainwater can be lacking in chemical elements that fish need to survive, such as chlorides and calcium. These chemical elements may have to be added to the system, especially when filling for the first time. RO water is also not ideal as it lacks all nutrients, hence low hardness levels, that may be beneficial to plant growth and fish health. RO water must be supplemented with minerals if it is to be used in an aquaponic system as the sole source of water. Growers are encouraged to send a water sample to a professional lab for an initial water quality profile. Additionally, the purchase of an RO system, chemicals, and filter membranes may add a great deal of cost to the operation of a system.

## IMPORTANT WATER QUALITY PARAMETERS

### Dissolved Oxygen

All life needs oxygen, including the life present in the water in an aquaponic system. The concentration of DO in water is important for optimal fish and plant growth, as well as for beneficial bacteria that convert toxic ammonia to usable nitrate ($NO_3^-$). In aquaponics, a DO level of 5 parts per million (ppm) or higher is recommended, although it may be higher depending on the species of fish being cultured. In general, for most warmwater species of fish, such as catfish and tilapia, DO concentrations of 3 ppm or less are stressful, and concentrations below 2 ppm can be deadly. For warmwater fish species, the general requirement is that the DO should never drop below 3 ppm, and a 30-day average should never be below 5.5 ppm. For coldwater fish species such as rainbow trout, the general requirement is that the DO should never drop below 4 ppm, and a 30-day average should never be below 6.5 ppm.

The time of day and season affect DO concentrations. In general, water holds less oxygen at higher temperatures. Therefore, water is able to hold higher concentrations of oxygen during the winter or early in the day when temperatures are lower compared to summer or late afternoon when temperatures are warmest. In aquaponics, the late afternoon is when DO levels are the highest due to photosynthesis of plants during sunlight hours, and early morning—around sunrise—is when they are lowest because no photosynthesis is occurring at night. Cloudy and rainy days cause DO concentrations to drop because there is less sunlight for plants to perform photosynthesis and produce oxygen. Too many fish in the tank, as well as too much food, can also deprive the fish of DO. Saline water, which is uncommon for aquaponics, also has less ability to hold DO than fresh water.

In a new system, it is recommended to measure DO levels frequently. They should be checked once a day at a minimum. Even after a system has stabilized, it is important to continue the daily monitoring of DO, as low DO is the largest threat to the survival of fish, the fastest way to lose all of the fish in a system, and most fish deaths during culture are a result of low DO. The biological demand for oxygen in a system changes daily. As the fish, plants, and bacteria population grow, they continually need more and more oxygen. Unfortunately, aquaponics growers do not usually measure DO because the equipment is expensive.

There are two ways to measure DO. The accurate—and more expensive—method is to use a DO meter (Fig. 1). Another method is to use the Winkler method, where manganese salt, iodide, and hydroxide react with water containing oxygen, an acid is added to convert and precipitate iodide to iodine, and the amount of DO is directly proportional to the amount of iodine that is titrated with a thiosulfate solution. This is the method with the lowest cost to measure DO, but chemical costs are more expensive in the long run than DO meters after hundreds of measurements. The Winkler method has also been converted to a colorimetric approach, in which the manganese is directly reacted with ethylenediaminetetraacetic acid to give a pink color, which can be read using a color wheel or spectrophotometer for greater accuracy. For additional information on DO measurements, visit *https://www.fondriest.com/environmental-measurements/measurements/measuring-water-quality/dissolved-oxygen-sensors-and-methods/*.

**Figure 1.** Two examples of meters available on the market for accurate measurements of dissolved oxygen in the water.

Diffused aeration using air stones or porous hose is mandatory in an aquaponic system, especially in the summer months with high water temperatures. Growers have successfully grown lettuce in an aquaponic system without added aeration in the winter months because cold water holds more DO. Air stones should be placed 3 to 4 feet apart in the plant trough, and additional air stones should be placed in the fish tanks and biological filtration tanks. Fish exhibit certain behaviors indicative of low oxygen levels in the water. When fish are oxygen deprived, they exhibit the following traits: appetite loss, "piping" or surface gasping, gathering around inflow pipes that contain more oxygenated water, reduced growth, and increased susceptibility to diseases and parasites.

## Total Ammonia Nitrogen (Ammonia, Nitrite, Nitrate)

Ammonia is excreted as the primary waste product of protein metabolism by fish from the gills and in urine. Ammonia in an aquatic system is in a constant state of fluctuation between toxic, unionized ammonia ($NH_3$) and non-toxic, ionized ammonium ($NH_4^+$) based on changing pH and temperature of the water. In an aquaponic system with a limited water volume, unionized ammonia concentrations can quickly reach levels toxic to fish, especially after feeding. Therefore, the levels should be monitored carefully. This is not normally an issue in a pond or lake, since the water volume is large compared to the number of fish present and the unionized ammonia is diluted.

Unionized ammonia is difficult to measure on its own. Therefore, total ammonia nitrogen (TAN) is measured, and then the concentration of unionized ammonia is calculated using the pH and temperature of the water. On its own, TAN reveals nothing about toxicity to fish, and pH and water temperature must be determined as well. When a water analysis is performed to determine TAN, you are determining the sum of unionized ammonia and ionized ammonium. Once TAN, pH, and temperature are determined, you can use any of a number of tables available on the internet based on calculations from Emerson et al.[1] The United States Department of Agriculture (USDA) Southern Regional Aquaculture Center has a fact sheet that contains these tables available at *https://srac.tamu.edu/fact-sheets/serve/111*. You can also download the Texas A&M AgriLife Extension Service AmmoniaCalc app for Apple devices, and simply plug in TAN, pH, and temperature to have the exact unionized ammonia concentration calculated for you. This app can be downloaded at *https://fisheries.tamu.edu/mobile-apps/*.

As the water pH or temperature increases, the proportion of toxic unionized ammonia increases. On the other hand, the proportion of toxic unionized ammonia decreases as water pH or temperature decreases. The concentration of ammonia that is toxic to each species of fish varies, but in general, aquaponics producers should start increased monitoring when unionized ammonia concentrations are found to be 0.25 ppm or greater. Most species of fish will begin to die when unionized ammonia concentrations are 0.5 ppm or greater, and water flushing should be initiated. To demonstrate how the toxicity of ammonia changes with pH and temperature, examples are listed in Table 2 at various TAN, temperature, and/or pH.

---

[1] (Emerson et al., 1975)

**Table 2. The effects of TAN, pH, temperature, and concentration of unionized ammonia and the resulting toxic/non-toxic condition in water**

| TAN | pH | TEMPERATURE | CALCULATED UNIONIZED $NH_3$ | CONDITION |
|---|---|---|---|---|
| 1.0 ppm | 8.0 | 80°F | 0.060 ppm | SAFE |
| 1.0 ppm | 8.0 | 95°F | 0.101 ppm | SAFE |
| 1.0 ppm | 9.0 | 80°F | 0.389 ppm | DANGER |
| 1.0 ppm | 9.0 | 95°F | 0.529 ppm | TOXIC |
| 2.0 ppm | 8.0 | 80°F | 0.120 ppm | SAFE |
| 2.0 ppm | 8.0 | 95°F | 0.202 ppm | SAFE |
| 2.0 ppm | 9.0 | 80°F | 0.779 ppm | TOXIC |
| 2.0 ppm | 9.0 | 95°F | 1.058 ppm | TOXIC |

Very high concentrations of TAN can be safe in a system if the pH and/or temperature are low. On the other hand, even small quantities of TAN can be toxic to fish if the pH and/or temperature are high. There are many simple and low-cost testing kits that measure TAN. A probe can be purchased that determines only ammonia concentrations, but these probes are extremely costly for the typical aquaponics producer.

In nature, two types of bacteria play a major role in converting toxic ammonia to the non-toxic nitrate that is readily used by plants. Ammonia is first oxidized to nitrite ($NO_2^-$) by *Nitrosomonas* spp. Nitrite is still toxic to fish but less so than ammonia, so it is wise to measure nitrite concentrations weekly to ensure the bacteria populations are functionally processing ammonia and that nitrite is not building up to toxic levels in your system. Nitrite toxicity in fish has been shown to be dependent upon the availability of chloride and calcium ions in the water. Higher concentrations of these ions can mitigate some toxicity effects of nitrite. For most warmwater species of fish, nitrite concentrations should be maintained at 1 ppm or less in aquaponic systems. In turn, nitrite is converted by *Nitrobacter* spp. to nitrate. Nitrate is relatively non-toxic to fish but can become toxic at extremely high concentrations. For most warmwater species of fish, toxicity is not reached until nitrate concentrations are greater than 100 ppm. For example, Monsees et al. found no adverse effects in juvenile Nile tilapia until nitrate levels reached 500 ppm.[2]

Nitrifying bacteria, including *Nitrosomonas* and *Nitrobacter* spp., grow on surfaces such as tanks and filters as a fixed film or on suspended organic particles. Nitrification is optimal at high DO levels and low levels of organic matter. Nitrifying bacteria are very sensitive to pH. *Nitrosomonas* spp. has an optimal pH of approximately 7.0 to 8.0, and the optimum pH range for *Nitrobacter* spp. is approximately 7.5 to 8.0. Nitrifying bacteria are inhibited and do not remove toxic nitrogen wastes at a pH of 6.0 and can begin to die at a pH below 5.5.

The nitrification process (from ammonia to nitrate) produces acid in the form of hydrogen ions ($H^+$), which lowers pH and reduces alkalinity, or the buffering capacity of a system. Therefore, pH in a well-maintained system tends to drop over time due to nitrification—additional details are presented in the pH section below.

The conversion of ammonia and nitrite and removal of nitrate is referred to as biofiltration. The biofilter often consists of the plant root surface and of the raft surface area, although larger and contemporary aquaponic systems utilize biofilters containing inert media similar to that used in high-density recirculation aquaculture systems. Studies at the University of the Virgin Islands showed that biofiltration occurs in the water column. For small systems, no additional filtration may be needed besides solid waste removal. However, in larger systems of a commercial operation, additional biofiltration is required, and a bed filter filled with Kaldness beads or other non-porous, high surface area inert is recommended.

A biofilter requires 4 to 6 weeks for sufficient bacteria populations to develop naturally and sufficient nutrients to build in the system for the plants. This means that a new system must be left for 4 to 6 weeks to grow the bacteria population before plants are added. During this initial period, fish must be fed at a very low rate, and growers must measure ammonia and nitrite daily to track their levels. The theoretical progress of converting ammonia to nitrate is shown in Figure 2, and a real-world example from a study conducted in 2014 is shown in Figure 3.

Another approach to establishing the biofilter is to artificially speed up the establishment of the bacteria population by inoculating the system with a starter solution containing

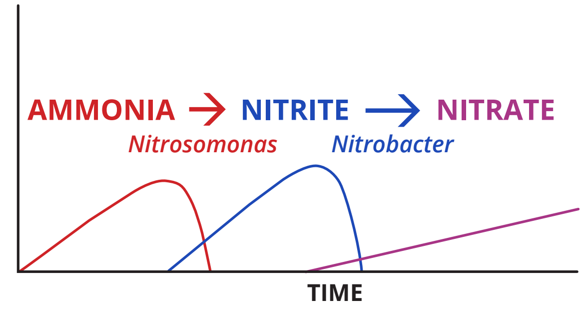

**Figure 2.** Theoretical progress of the conversion of ammonia to nitrate through the action of *Nitrosomonas* and *Nitrobacter.*
*Source: The Federation of British Aquatic Societies*

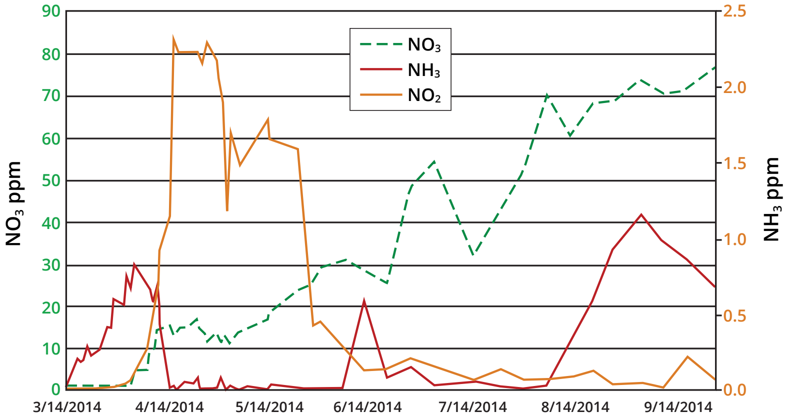

**Figure 3.** Actual progress of the conversion of ammonia to nitrite to nitrate over time.

---

[2] (Monsees et al., 2017)

*Nitrosomonas* spp. and *Nitrobacter* spp. (Fig. 4). Several commercial starter cultures of bacteria are available from various manufacturers. A food source for the bacteria must be added to the system. The ideal food choice is clear ammonia (Fig. 5) at a concentration of 20 ppm, but this concentration is toxic to fish, so the ammonia must be effectively converted to nitrate before adding fish to the system. Once the system is filled with water and aerated for a couple of days to release carbon dioxide ($CO_2$) and any chlorine (Cl) gas, add the bacteria starter solution and clear ammonia. In a 1,000-gallon system, add 2.5 fluid ounces of clear ammonia. Then, measure ammonia, nitrite, and nitrate daily using a commercially available test kit (Fig. 6).

**Figure 4.** Example of a starter solution containing *Nitrosomonas* and *Nitrobacter* bacteria that can be used to speed up the initial startup of a new system.

**Figure 5.** Clear ammonia is used as a source of ammonia for the bacteria in the starter solution to speed up the proliferation and establishment of bacteria in a new system.

**Figure 6.** The Freshwater Master Test Kit includes tests for high and low pH, ammonia, nitrite, and nitrate.

The system is ready when ammonia and nitrite rates are at nearly 0 ppm, and nitrate is at least 10 ppm. Additional clear ammonia may be needed to be added to maintain 20 ppm ammonia levels until 10 ppm of nitrate is detected. Do not wait too long to add fish and to start feeding once the ammonia and nitrite rates are at nearly 0 ppm and nitrate is at 10 ppm, or the bacteria populations will starve and collapse.

In addition to the drastic effects of low DO levels on both plant and bacteria health, another problem with low DO levels is a process called denitrification. Under anaerobic—or no oxygen—conditions, denitrifying bacteria convert nitrate to nitrogen gas ($N_2$), which increases alkalinity and pH, and the primary plant food source is lost to the atmosphere as a gas. Therefore, regular attention is needed to maintain air supply and ensure consistent DO levels in the system. Proper control and maintenance of nitrate concentrations are also important for the long-term health of an aquaponic system. Nitrate concentrations are regulated by the frequency of fish feeding and filter tank cleaning. Frequent filter cleaning—twice a week—will increase nitrate levels and is good when growing leafy greens. Less frequent cleaning—less than once a week—will tend to decrease nitrate levels and is a good approach when growing fruiting vegetables.

## pH

pH means “potential of hydrogen” or “power of hydrogen” and is a measure of the $H^+$ ion concentration in the water. A low pH value means a high concentration of $H^+$ ions and that the solution is acidic, with a pH range of 0 to 7. Similarly, a high pH indicates a basic pH, with a range of 7 to 14 and a low concentration of $H^+$ ions. A pH of 7 is considered neutral. pH is considered the master variable because it influences water quality parameters such as the ratio of ammonia to ammonium and the solubility of plant nutrients. A well-designed and properly operating aquaponic system is one where pH is constantly decreasing due to nitrification and needs to be adjusted up to the optimal pH of 7. Therefore, it is essential to regularly test pH to determine if normal aerobic conditions are present and to avoid drastic changes in pH, which can be fatal to fish, plants, and bacteria.

It is recommended to measure the pH of a new system daily until it reaches a stable state and the operator is familiar with the effect of the seasons and other practices on water pH. When the system is stabilized, less frequent measurements, around twice per week, are acceptable.

As mentioned earlier, the ideal situation creates a pH that tends to drop over time. A situation where pH does not decline over time is detrimental, typically due to one of two reasons: that calcium and potassium are not being supplemented to the system, which will affect plant health and productivity, or that denitrification is occurring in anaerobic zones and nitrate is being converted to nitrogen gas. Denitrification consumes $H^+$ ions and increases pH. Some alkalinity is produced by plants, but most significant alkalinity is produced by the denitrification process. To avoid anaerobic conditions and the resultant denitrification, it is recommended to clean filter tanks twice a week and remove deposits of organic matter from filters.

Low pH conditions are just as detrimental to an aquaponic system as high pH conditions. Sometimes, the operator neglects to measure pH for several days, and the pH can quickly decrease to below 5.5. At a pH below 5.5, nitrification has largely ceased, and TAN concentrations can become extremely elevated. It is necessary to remedy this condition by adding a base very slowly over several days. Do not add a large amount of base at one time, as this will shift most of the TAN into the toxic unionized ammonia and kill all the fish.

Most species of warmwater fish can tolerate a wide range of pH from 5.5 to 10. For example, tilapia can tolerate a pH from 5 (acidic) to 10 (basic). However, the optimal pH range for growth and reproduction is much narrower, from a pH of 6.5 to 9 for most warmwater species. For example, Nile tilapia growth is optimized at a pH range of 7 to 8, which is on the basic side of the scale. Since plants prefer a pH less than 6.5 and the nitrifying bacteria perform optimally at a pH of 7.5 to 8, maintaining a system pH of 7 is a compromise that meets the basic needs of plants, fish, and bacteria.

There are simple ways to adjust the pH. Bases, and less often acids, can be added in small amounts to the water in order to increase or lower the pH, respectively. Acids and bases should always be added slowly, deliberately, and carefully. The water should be allowed to circulate and stabilize for several hours before measuring pH or alkalinity again to determine if additional acid or base is needed. Alternatively, the addition of rainwater can be used to naturally lower the system pH by diluting alkalinity and allowing nitrifying bacteria to acidify the system. Calcium carbonate from limestone or crushed coral buffers pH against natural acidification. When adjusting pH, alternate the use of calcium hydroxide with potassium hydroxide in the base addition tank to ensure the addition of nutrients for plants.

## Hardness

Hardness is often confused with alkalinity. Hardness measures the amount of calcium (Ca) and magnesium (Mg) concentrations in the water and is expressed as equivalent to calcium carbonate in ppm. Alkalinity refers to the amount of calcium carbonate ($CaCO_3$) and bicarbonate ($HCO_3^-$) in the water and ranges from soft water (0 to 75 ppm) to very hard water (>300 ppm). Alkalinity is a measure of the ability of a solution to neutralize acids. Water with high alkalinity will resist pH changes as it contains high levels of carbonate and bicarbonate ions. RO water is an example of low alkalinity water, since it does not contain any ions, and the pH will drastically change with any addition of an acid. Since calcium and magnesium react and bond with carbonates and bicarbonates, alkalinity and water hardness are closely interrelated. For freshwater fish, acceptable alkalinity is 20 ppm or more (as calcium carbonate), while optimal alkalinity for growth and reproduction is 50 to 150 ppm. The optimal hardness for growth and reproduction of most warmwater fish is 50 to 150 ppm.

In aquaponics, water should have sufficient calcium, magnesium, carbonate, and bicarbonates. In other words, water should be maintained at 100 ppm calcium carbonate or above in slightly hard water or higher.

## Water Temperature

Fish are temperature-dependent, and the ideal water temperature varies with fish species and plant species used in an aquaponic system. For example, tilapia can tolerate temperatures from 55 to over 100°F but prefer 81 to 84°F for maximum growth. Tilapia growth slows dramatically and reproduction stops at temperatures below 70°F. Depending on the species of tilapia, death occurs when the water temperature is 45 to 55°F. The probability of disease also increases at extremely low or extremely high temperatures, as fish are stressed. Vegetable roots prefer a water temperature of 70 to 75°F for optimal growth. Aquaponics growers keep their tilapia fish tanks at 72 to 78°F as a compromise between the ideal temperature for fish and plants.

Water temperature also affects the oxygen level held in the water and the amount of unionized ammonia not yet converted to nitrite ions. Warm water can hold less oxygen than cold water (Table 3). Warm water also has a greater proportion of unionized ammonia, but this effect is only important when the pH is greater than 7. In general, at a pH of 7 or below, almost 100 percent of the TAN is in the non-toxic ionized form ($NH_4^+$). It is recommended to measure the water temperature daily.

**Table 3. Oxygen solubility (ppm) as affected by water temperature**

| TEMPERATURE (°C) | TEMPERATURE (°F) | OXYGEN SOLUBILITY (PPM) |
|---|---|---|
| 0 | 32 | 14.6 |
| 5 | 41 | 12.8 |
| 10 | 50 | 11.3 |
| 15 | 59 | 10.2 |
| 20 | 68 | 9.2 |
| 25 | 77 | 8.6 |
| 100 | 212 | 0 |

Modified from *Washington State University Ecology Citizen's Guide to Water Quality*

## Alkalinity

Alkalinity and pH are often confused as the same measure. This may be because adding a base increases alkalinity in the water in addition to increasing pH. This confuses people into thinking that a high pH means high alkalinity as well. However, the pH of water can be high but have almost no alkalinity, which means it has little buffering capacity against acids and rapid pH changes. While pH measures the concentration of $H^+$ ions in water and qualifies water as acidic or basic, alkalinity is a measure of the buffering capacity of water and its ability to resist changes in pH.

Water with low alkalinity is very susceptible to large or rapid changes in pH. Water with high alkalinity can resist major changes in pH. Alkalinity is expressed as the equivalent concentration of calcium carbonate required to bring a sample of water to a specific pH. The acceptable level of alkalinity in aquaponics has a broad range between 50 and 300 ppm. However, it is recommended that growers maintain alkalinity between 50 to 150 ppm, preferably above 100 ppm.

## Carbon Dioxide

Carbon dioxide levels should not exceed 20 ppm. At higher levels, the fish become sluggish and cannot absorb enough oxygen through their gills. In systems with diffused aeration, carbon dioxide buildup is not a problem because it is vented off to the atmosphere through agitation of the water. Carbon dioxide buildup is a problem in aquaculture systems using pure oxygen, but the use of pure oxygen is expensive and typically not necessary to support fish densities in aquaponics.

## Settleable Solids

Settleable solids, such as feces, uneaten feed, and biological growth, are larger solids that are denser than water and quickly settle to the tank bottom. Settleable solids should be removed during the first stage of filtration in an aquaponic system. Clarifiers and swirl separators are recommended for passive solid waste removal, although a simple sump tank can also be effective if water flow is diffused using screens or media. A 20-minute retention time is required for clarifiers to effectively separate and settle solids before the water reaches the grow beds. Another approach to effectively filter settleable solids is to use a bead or sand filter. As water enters the filter under pressure, the solids become trapped among the inert plastic beads or grains of sand. The bead or sand filter is regularly backwashed to remove the solids through a separate drain. Regular flushing of waste solids is recommended, and cleaning frequency depends on the size of the aquaponic system and the fish stocking density. We recommend starting with a biweekly flush, with the frequency adjusted to meet the needs of your system.

## Suspended Solids

Fine solids too small to settle in a swirl filter or become trapped in a bead/sand filter are called suspended solids. They are removed by being trapped in filters or screens, which can be fashioned from numerous materials such as orchard netting, fiber floss, and several specialized aquaculture materials. Suspended solids are typically organic-based. As these organic solids decompose, essential nutrients are released and taken up by plant roots by a process called mineralization. The filter tanks should be cleaned when the water flow reduces, typically once or twice a week for optimal performance and to avoid a buildup of solids on plant roots. At the same time, do not clean the filter tanks too frequently, as that will remove a valuable source of minerals to the plants.

## Water Quality Testing

As mentioned above, simple chemical titration or color change test kits are available for homeowners and commercial growers alike to test essential water quality parameters, such as pH, ammonia, nitrite, and nitrate. Many chemical titration or color change test kits (Fig. 6) are reasonably priced and are a great start-up tool for accurate measurements.

For scientific research, commercial production, or for more accurate measurements, many companies provide digital meters for measuring pH, electrical conductivity, DO, and temperature. A pH meter can cost anywhere from about $30 to a few hundred dollars (Fig. 7), and DO meters can cost a few thousand dollars. Spectrophotometers (Fig. 8) are also available for accurate measurements of individual parameters. Additionally, certified labs are available that measure water quality parameters.

**Figure 7.** A digital meter for measuring pH, electrical conductivity (EC), and the temperature of water.

**Figure 8.** A spectrophotometer used for accurate measurements of various nutrients in water. This one is used for measuring nitrate.

## BIBLIOGRAPHY

1. Durborow, Robert M., David M. Crosby, and Martin W. Brunson. (1997). *Nitrite in Fish Ponds.* Southern Regional Aquaculture Center. Publication No. 462.
2. Durborow, Robert M., David M. Crosby, and Martin W. Brunson. (1997). *Ammonia in Fish Ponds.* Southern Regional Aquaculture Center. Publication No. 463.
3. Emerson, Kenneth, Rosemarie C. Russo, Richard E. Lund, and Robert V. Thurston. (1975). *Aqueous ammonia equilibrium calculations: Effect of pH and temperature.* Journal of the Fisheries Research Board of Canada. 32, pp. 2379–2383.
4. Fondriest Environmental, Inc. (2014). *Measuring Dissolved Oxygen.* Fundamentals of Environmental Measurements. Web. Retrieved from: https://www.fondriest.com/environmental-measurements/measurements/measuring-water-quality/dissolved-oxygen-sensors-and-methods/.
5. Monsees, Hendrik, Laura Klatt, Werner Kloas, and Sven Wuertz. (2017). *Chronic exposure to nitrate significantly reduces growth and affects the health status of juvenile Nile tilapia (Oreochromis niloticus L.) in recirculating aquaculture systems.* Aquaculture Research. 48(7) pp. 3482–3492.
6. Somerville, Christopher, Moti Cohen, Edoardo Pantanella, Austin Stankus, and Alessandro Lovatelli. (2014). *Small-scale aquaponic food production. Integrated fish and plant farming.* FAO Fisheries and Aquaculture Technical Paper 589.
7. Stone, Nathan, Jay L. Shelton, Brian E. Haggard, and Hugh K. Thornforde. (2013). *Interpretation of Water Analysis Reports for Fish Culture.* Southern Regional Aquaculture Center. Publication No. 4606.
8. Wurts, William A. and Robert M. Durborow. (1992). *Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds.* Southern Regional Aquaculture Center. Publication No. 464.