Aquaponic System Design Parameters:

Basic System Water Chemistry

Wilson Lennard PhD

Aquaponic systems range from those designed for hobby or backyard food production through to those designed for commercial scale production of fish and plants for sale. In either context, or any in between, management for optimisation and efficiency of the system is paramount to success. One of the keys to the management of aquaponic systems is via an understanding, and the ability to manipulate, system water chemistry.

An understanding of water chemistry and how it affects the biological aspects of the system (fish, plants and bacteria) is critical to technical success. Knowing and being able to manipulate the water chemistry of an aquaponic system will allow the operator to get the best out of the system possible and to ensure that the plants, fish and bacteria are in an environment that is amenable to their living requirements.

In this fact sheet we will take a look at what basic water chemistry parameters are essential to optimised aquaponic system operation.

The Responsibility We Have For Our Fish

Fish are living animals and because of that, we have a responsibility to make sure we are keeping our fish in the best conditions possible; to give them the least stressful life that we can.

Many people are now very disconnected to the food that we consume, especially the animals we consume. Farming has become something that "occurs somewhere else" to many city dwellers. Even though this disconnection is common place to many of us who live in the city, the majority of us agree that the animals we eat should have the best and least stressful life possible. Fish should be no different in this sense and if we all agree that the animals we eat should be cared for correctly, then fish are no exception.

In an aquaponic context therefore, we all have a duty of care towards the fish we keep and one of the most important aspects of our fish keeping is making sure we provide our fish with the best water quality we possibly can. This is because fish live in an aquatic environment and so the chemistry associated to that aquatic environment has a critical effect on the fish's well-being and health.

Bacteria

There are three important biological inhabitants of our aquaponic systems; fish, plants and micro-organisms. The micro-organisms that inhabit any aquaponic system can also be sub-classified into a further array of organisms which include, but are not limited to, bacteria, fungi, phytoplankton and zooplankton. All of the biological inhabitants of an aquaponic system contribute to the ecosystem nature of the aquaponic system.

The bacteria in our aquaponic systems are critical to the operation and ecology of the system and if they were not present, then aquaponics would have little, if any, chance for success. This is because the bacteria perform critical processes that lead to, assist and drive the biological balance of the system. It is these bacteria that perform chemical processes in the water that makes the water liveable and usable by the fish and the plants that we wish to grow.

Bacteria are so small that they cannot be seen by the naked human eye. However, they can also make up a large proportion of the overall system biomass (biomass is the weight of all the living things in a system). So, whilst we cannot see them, we must accept that they are there,

there are large numbers of them, there are many different species of them and they are critical to the overall chemical and biological health of the system.

Bacteria do utilise some of the nutrients contained in the aquaponic system. They use elements like carbon, oxygen, nitrogen, phosphorous, potassium and calcium, along with many others, to build there own cells, just like we do, fish do and plants do. However, bacteria gain access to the energy they require by performing and assisting chemical reactions that release energy.

For example, nitrification, the conversion of ammonia to nitrate is mediated (performed) by several species of nitrification bacteria in aquatic systems. The reason the bacteria convert ammonia to nitrate is not because these bacteria like or prefer nitrogen in the form of nitrate more than nitrogen in the form of ammonia (unlike our fish, to which ammonia can be toxic). The reason is that when ammonia (NH_3) is converted to nitrate (NO_3) the exchange of hydrogen ions (H) for oxygen atoms (O_2) releases energy, and it is from this energy source that bacteria derive the energy to run their own metabolism. Similar processes occur inside humans when we eat and the release of this energy is used by us for vital life processes such as keeping warm and having energy reserves so we are able to walk, run, swim etc…

Therefore, bacteria perform these chemical conversions and exchanges not because they require a specific nutrient, but because they derive their energy requirements by performing these chemical exchanges that release energy.

It is a positive by-product of this ability of the bacteria in our aquaponic systems that they also perform chemical conversions that are critical for fish and plant health.

Like any aquatic organism, the bacteria in aquaponic systems are dependent on the water as the medium within which they live their lives. Therefore, bacteria are also dependent upon the water being in the best chemical condition it can be so they live in an environment that is amenable to their continued health and well-being.

Fish

Like bacteria, fish live in the water environment and so they are also dependent on the water to deliver a living condition that is right for them. The fish's skin (often covered in scales) is open to water movements across it and so the condition of the water can quickly affect the internal parts of the fish.

In addition, fish "breath" via gills which are highly efficient devices with a large surface area that allow oxygen to enter the fish's body and carbon dioxide to escape; just like our lungs do. We know that there can be substances in the air, or poor air quality conditions, that can affect our own breathing and ability to gain access to the oxygen we require to live. Fish are similar except that instead of air, they live in water. Therefore, the chemical condition of the water is critical to the ability of the fish to gain access to the oxygen they require; if it is of sub-optimal quality then it can affect the efficiency of the fish's gills.

Fish gills do not just act as a site for oxygen and carbon dioxide exchange. They are also the site where other elements may enter the fish (as dissolved gases in the water) and they are the site where the fish expels the products of some of their metabolic processes. Ammonia is expelled as a gas across the fishes gill and directly and immediately dissolves into the water. If nitrite levels are too high in aquaponic systems, then the nitrite can affect the fish and this occurs because the fish "breathes in" the nitrite across its gills and then the nitrite dissolves into the fish's blood and causes problems (often called "brown blood" disease). This demonstrates that the fish are entirely dependent on what is dissolved in the water as to whether they may experience negative or positive outcomes.

So fish, like the bacteria, are also dependent upon the water being in the best chemical condition it can be so they live in an environment that is amenable to their continued health and well-being.

Plants

Plants are an interesting life form in that they have parts of them that need to deal with these two main environments; air (at the leaf and stem surfaces) and water (at the root surfaces). The roots themselves need to be able to deal with these two environments of air and water; sometimes they are dry and exposed to the air within the medium that they are growing in, and sometimes they are wet due to the water that surrounds them in the medium. Therefore, plants are exposed to the air and so need good air quality and they are exposed to water, and so also need water conditions that suit them and the processes that occur at the root surface.

In aquaponic systems, the fish produce waste, that waste is processed by the bacteria and the processed waste is then taken up by the plants as nutrients. Plants do not filter out nutrients and leave the water behind; they gain access to the nutrients by taking water in across their root surfaces and because the nutrient is dissolved in the water. Therefore, plants are constantly taking up and internalising water and so the quality of that water is critical so that it doesn't upset the plant when internalised.

The nutrients that the plant is taking up across its roots can also be affected by the chemistry of the water and if the water chemistry is incorrect, this can manipulate the chemical form that the nutrient is in and this can mean that the nutrient is either in a form that the plant does not prefer, or is in a form that the plant cannot even access. Hydroponic farmers well know that if the pH of their water is incorrect, then this can stop the plant from gaining access to the nutrients and this is seen as nutrient deficiency.

So, plants, like the fish and bacteria, are also dependent upon the water being in the best chemical condition it can be so they live in an environment that is amenable to their continued health and well-being.

Water

Water (H_2O), as can be seen, consists of two hydrogen atoms attached to an oxygen atom. In reality, water is actually the combination of one hydrogen ion (H^+) and one hydroxyl ion (OH^-). Water is a far more complex substance in many respects, than most people know. It is also very complex in a chemical sense.

Water is in a constant chemical flux (change) between its main water molecule (H_2O) and the two constituent parts of the water molecule; hydrogen ions (H^+) and hydroxyl ions (OH^-). The water molecule is constantly dissociating into the two constituent parts and they are then constantly reforming into the water molecule again.

This means water is in a constant state of chemical flux and this means that water is a highly reactive element that can be affected by many chemical forces. Many substances dissolve into water, many substances do not dissolve, some substances can both dissolve and not dissolve at different times and depending on different chemical conditions in the water. Water can dissolve gases from the air and atmosphere and water can dissolve solids that enter into it. Water can also dissolve both gases and solids that are generated by fish, bacteria and plants.

This chemical ability of water to be many things to many different substances is best expressed as water chemistry. By understanding the chemical nature of water and using these properties to our advantage, we can manipulate the water chemistry so it provides the best conditions for all the life we wish to grow in it; the fish, plants and bacteria.

pH

pH (often referred to as "The **P**ower of **h**ydrogen) is a measure of the ratio of hydrogen ions (H^+) to hydroxyl ions (OH^-) within a water body. The scale of pH is between 0 and 14; with a pH of 7 being known as "neutral pH".

When the pH drops below neutral 7 it is because we have a higher proportion of hydrogen ions (H^+) than hydroxyl ions (OH^-) and this state is known as being “acid”. When the pH rises above neutral 7 it is because we have a higher proportion of hydroxyl ions (OH^-) than hydrogen ions (H^+) and this state is known as being “basic” or “alkaline”.

Fish have an internal pH of about 7.4 and because the water they are swimming in can cross their skin and be internalised, they like the surrounding water to be at approximately the same pH. Therefore, if the pH of the water that the fish are living in is either too low, or too high, then this can upset the internal pH balance of the fish and cause problems and even kill the fish.

Bacteria are similar to fish and have their own internal pH. Again, like fish, the water that the bacteria are living in, or are exposed to, should be similar to the internal pH of the bacteria or problems may arise and they can die. For example, the nitrification bacteria that we rely on to convert potentially toxic ammonia that is released from the fish to non-toxic nitrate, like a pH between approximately 6.5 and 8.0. If the water pH goes too high or too low then the bacteria stop metabolising and can die.

Plants also have an internal pH set point that is best for them. As we have seen, plants are almost constantly taking in water through their roots and releasing it through their leaves, so they are internalising the water they are exposed to. Again, like the fish and the bacteria, if the water that the plant is exposed to is too far away from the plants internal pH, then problems may arise.

Plants also like nutrients to be in certain forms so they can metabolise them and use them to build themselves (ie: grow). The pH of the water can directly affect the chemical form of a nutrient and if this is not the right chemical form, then the plant may not be able to metabolise or utilise the nutrient and will then show nutrient deficiency.

Therefore, the pH of the water is critical to all the life that inhabits our aquaponic systems and if we control the pH so that it sits somewhere that will meet the requirements of all the life in our systems, then we will have a balanced system with the living conditions, in terms of pH, that all our aquaponic life requires.

To complicate things further, many of the biological processes which occur in an aquaponic system can, and do, affect the water pH. For example, when fish release ammonia waste across their gills and it dissolves in the water, the nitrification bacteria quickly convert that ammonia to nitrate. That conversion occurs because the bacteria assists a chemical reaction where the hydrogen ions attached to the nitrogen atom in the ammonia molecule are removed and replaced with oxygen ions. This means that this reaction (or conversion) causes a net release of hydrogen ions into the water.

As we have seen, when there are more hydrogen ions in the water than hydroxyl ions, the pH drops and turns the water acid. This nitrification reaction that the bacteria perform for us is the principle reason the pH constantly drops in correctly operating aquaponic systems. This constant pH drop in aquaponic systems indicates that the biological processes we want to occur in the system are occurring and therefore, is a key indicator of system health.

Plant processes can also affect system water pH. When plants take up nutrients, principally nitrate, they release what is known as bi-carbonate ions (HCO_3^-). The plant does this to balance the internal electrical charge within their roots (nitrate is also a negatively charged ion, so the plant releases bi-carbonate as they have it in abundance and because it is also negatively charged; this balances the electrical charge state within the plant root). Bi-carbonate scavenges hydrogen ions (H^+) in water and therefore, removes hydrogen ions from the water body. This means that the hydroxyl ions begin to dominate and so the water pH rises above neutral 7 and therefore, becomes basic (or alkaline).

Therefore, in aquaponic systems we have two prominent and opposite forces operating that directly affect the pH of the water body; the bacterial conversion of fish waste ammonia to nitrate (causing a pH drop) and the plant release of bi-carbonate when taking up nitrate (causing a pH rise). The reality is that the pH drop caused by the conversion of fish waste ammonia by the bacteria to nitrate causes more hydrogen ions to be released than the plant release of bi-carbonate ions when taking up nitrate. Therefore, in properly designed, managed and balanced aquaponic systems (in this case proper balance means the balance between fish and plants) we should still see a regular and steady drop in system water pH.

We should test our pH on a regular basis for these two major reasons:

1. To make sure the pH is constantly dropping, which is an indicator that things are operating correctly on a biological and chemical level.

2. To assist us in working out how often, and by how much, we need to buffer the water.

I recommend that all aquaponic systems should be tested for pH every day. In some cases, this daily testing is not required as the pH drop experienced over a 24 hour period is minimal (eg: 0.1 – 0.2 pH units). This can only be determined with the particular aquaponic system being operated. I like to test pH every day and I like to buffer every day so that I have as full an understanding of what is happening chemically in my systems. The advantage of doing pH tests and buffering every day is that it usually means that the pH is only dropping minimally and then after buffering, the pH is only rising minimally.

The minimal movement in pH over a short period of time is important to the living organisms in our aquaponic systems. Fish, for example, will, over long periods of time, adapt to quite acid water (I have seen fish in water of pH 4.5 still living). This doesn't mean a pH of 4.5 is acceptable for fish to be living in and in all likelihood, whilst they are still living, they may be severely stressed. The fish can adapt to this low pH because the time it has taken for the water to move from neutral 7 pH to this low level takes long periods of time (weeks). If this drop was to occur in a couple of days, then the fish would die. Fish do not like large swings over short periods of time in water chemistry. Therefore, keeping the swings to a minimum is what the fish will like best. This is why I advocate daily pH testing and buffering, as it keeps these swings in pH to a minimum.

Properly designed aquaponic systems should operate in what is known as an "aerobic" state. An aerobic state is one where plenty of oxygen exists in the water and the surrounding media. When we have an aerobic state, we have particular chemical conditions that are advantageous to the system. In addition, the bacterial species that dominate the system are aerobic in nature; meaning they require oxygen to live and do the conversions they do.

Nitrification, the conversion of ammonia to nitrite, then nitrate, is performed by aerobic bacteria. There are also bacterial species that will breakdown, mineralise and dissolve fish waste solids back into the water under aerobic conditions. Nitrification is a critical process in aquaponic systems as ammonia may be toxic to the fish and bacteria. All aquaponic systems should be operated under aerobic conditions.

What happens chemically to the water if anaerobic conditions (low or zero oxygen conditions in the water or media) prevail? In anaerobic conditions, a different set of bacteria operate. These anaerobic bacteria can also perform many chemical conversions. The one we are most interested in for aquaponic systems is related to nitrogen.

When ammonia is converted to nitrate, the process is called nitrification. In anaerobic conditions, de-nitrification can occur where the bacteria convert nitrate to other chemical forms. One of the results of this de-nitrification is that nitrate is converted back to nitrite, and as we know, nitrite is toxic to fish. When de-nitrification operates (under anaerobic conditions), the nitrogen in the aquaponic system can become many different forms and actually eventually is converted to nitrogen gas (N_2) which bleeds out of the system.

The de-nitrification process has another, more important outcome; it makes the pH of the water in the aquaponic system rise. If too much de-nitrification occurs (because we have too many anaerobic zones in the system), the pH can actually rise all the way back up to neutral 7 and often go above this. As we will see in the next section, this is not good, as it stops us form adding the buffers we need to adjust pH and to supplement potassium (K) and calcium (Ca); nutrients which are essential for plant growth.

All well designed and managed aquaponic systems should operate under aerobic conditions where the pH is constantly falling. Therefore, testing pH regularly helps us to determine if the normal aerobic operating conditions are present. If they are not, then pH won't fall and this is a key indicator that anaerobic conditions may be prevailing.

Buffering to Manipulate System pH

As we have seen, in a properly operating aquaponic system the pH of the water should be constantly dropping towards acid. If we allow this to continue unabated, then we take the risk of allowing the system water pH to drop to a point where it goes outside of the optimum requirements for all the life in the system. Therefore, if it is within our power, we should try to make sure that the pH stays at the optimum.

This introduces the question of "what is the optimum operating pH for an aquaponic system?" There are many different opinions on this. However, it is fairly universally agreed that aquaponic system water pH should be somewhere close to neutral 7. I personally operate my systems at a target pH of 6.8. The reasons for this are two-fold:

1. When the system water pH is slightly below neutral 7, if there is any ammonia in the system then the majority of that ammonia is in a non-toxic form.

2. Many plants actually like a pH of around 6. This is because at this slightly acid state, the nutrients dissolved in the water are in the chemical state which the plants prefer.

No matter where you decide your pH target is, the fact remains that in a properly operating aquaponic system, the constant drop in the water pH must be counter-acted in some way.

The way we do this is by the addition of what is known in aquaponics as a "buffer".

Buffers act by adding ions to the water that scavenge the predominating hydrogen ions and removing them from being chemically available to the system. In this way, by the removal of some of the hydrogen ions, we can make the pH rise back towards our target set point. Because pH constantly drops to an acid state via the chemical processes outlined above, it makes sense that buffer addition must be a regular operation.

The most often used buffer in recirculating aquaculture systems (RAS) is sodium bi-carbonate ($NaHCO_3$). Buffers are made up of two parts:

1. The basic or alkalising portion (the portion which makes the pH rise).

2. The "carrier" ion portion (this portion allows the buffer to be a solid when not in water, which makes it easy to store and control).

In the sodium bi-carbonate buffer mentioned above, the alkalising portion is the bi-carbonate ion (HCO_3^-); this is the portion that controls the pH and causes it to rise. The carrier ion is the sodium (Na^+). Sodium bi-carbonate is a solid when not in water because the sodium and the bi-carbonate have formed a bond between them. When we add the sodium bi-carbonate to the water, it immediately dissolves and releases the two portions so they are "free agents", so to speak. The bi-carbonate (HCO_3^-) scavenges the free hydrogen ions (H^+) and removes them from being chemically active and raises the pH. However, we now have a number of sodium ions (Na^+) also dissolved in the water; what happens to these? Well, in fact, nothing! They are left in the water body and so over time, they accumulate or build up.

Plants do not like sodium to be dissolved above certain concentrations in water. Bacteria also dislike this. And, if the sodium concentration gets way too high, even the fish may be affected. Therefore, it makes sense that sodium bi-carbonate may not be the ideal buffer for aquaponic systems.

This means we need to find a buffer with a different carrier ion; one that maybe won't accumulate in the system. In fact, there are many other buffers available.

Plants require good amounts of other nutrients that aren't always available via the fish food and the associated fish waste. The two major ions (nutrients) that the plants need, but are limited in fish food, are potassium (K^+) and calcium Ca^{++}). It therefore makes sense to try and use buffers based on these two essential plant ions.

There are a few choices with respect to buffers that use potassium or calcium as carrier ions. With respect to calcium, we can use calcium carbonate ($CaCO_3$), calcium bicarbonate ($Ca(HCO_3)_2$), calcium oxide (CaO) or calcium hydroxide ($Ca(OH)_2$). Calcium forms buffers that are often difficult to dissolve in water at the pH values that aquaponic systems operate at. This means that they do not dissolve all that easily and solid, undissolved calcium buffers may even drop out to the bottom of tanks in the system. In this sense, one of the easiest buffers to dissolve is calcium hydroxide (also known as hydrated lime). This is the calcium buffer I use in my systems and it is also the buffer that James Rakocy and UVI advocate.

With respect to potassium, we can use potassium carbonate (K_2CO_3), potassium bi-carbonate ($KHCO_3$) or potassium hydroxide (KOH). I use potassium carbonate as it readily dissolves and it carries twice the amount of potassium that other buffers do. UVI uses potassium hydroxide. Potassium bi-carbonate also readily dissolves, so any of these choices are OK for aquaponic systems.

When we use these calcium and potassium based buffers, two essential things occur. Firstly, the alkalising portion controls the system pH and raises it back to where we choose for it to be. The second thing these buffers do is actually supplement the system with the major nutrients required for plant growth that are lacking in the fish feed; calcium and potassium.

Therefore, when these buffers are applied correctly they control the pH in a situation where we also do not get an accumulation of the carrier portion, because the plants actually use the carrier portion.

The amount of buffer to add is an inexact process. It can be mathematically calculated, however, in my experience, every aquaponic system operates slightly differently and so it is far better to experiment with the system itself to determine an approximate daily buffer requirement. This is simply done by adding only small amounts of buffer daily until a trend is seen in the total amount required. Thereafter, if the same amount of fish feed is being fed daily, then the amount of buffer required should be similar every day. After a couple of weeks it is easy to begin to predict how much buffer is required for a particular system to raise the pH to the desired level.

As we have seen above, if anaerobic conditions prevail, then the pH will not fall and therefore, we cannot add any of the potassium and calcium supplementation required to give the plants all the nutrients they need. Therefore, anaerobic conditions in aquaponic systems should be avoided.

Dissolved Oxygen (DO)

Most of the organisms that exist in our aquaponic systems like oxygen to be present. The fish, like us, require oxygen to breathe and live. If there is not enough oxygen in the water then the fish die of asphyxiation due to a lack of oxygen they require in the blood to perform the metabolic processes they rely on. Fish remove oxygen directly from the water via their gills, so the only oxygen that matters to fish is that which is dissolved (and therefore, available) in the water column.

Most of the bacteria we like to see in our aquaponic systems are called "aerobic"; which means they require oxygen to live. There are other bacteria that do not like oxygen and only operate in super-low, or zero, oxygen environments. These bacteria are called "anaerobic". Anaerobic bacteria utilise different chemical pathways than aerobic bacteria and if we get too many of them in our aquaponic systems, they can have negative affects (like the release of poisonous gases that dissolve directly into the water). In addition, the bacteria we rely on the most in our aquaponic systems, the "nitrifiers" (which convert potentially toxic ammonia to non-toxic nitrate), are fully aerobic and require good concentrations of dissolved oxygen in the water to operate efficiently.

Plants take in most of their oxygen from the air via their leaves. However, plant roots like good levels of dissolved oxygen to be in the water that is close to their roots. This oxygen makes it easier for the plant to transport nutrients across its root surfaces and internalise them. Also, many plant root pathogens operate at low dissolved oxygen levels, so if the water is low in oxygen it can give these pathogens the chance they need to attack the roots.

The outcome is that we need acceptable concentrations of dissolved oxygen in our aquaponic system water at all times.

There are several ways to increase dissolved oxygen levels in aquaponic system water. Splashing water onto surfaces (as is done when water inlets or returns to fish tanks break the surface) will increase dissolved oxygen. This is because the splashing water increases the surface area of the water body, and the amount of gas exchange to a water body from the atmosphere is directly proportional to the surface area of the water body.

The most often used way to increase dissolved oxygen concentrations in water is via aeration. This is mostly done by using air pumps to pump air into the water body via an airline and an air stone. Air stones make smaller bubbles, which assists oxygen exchange across the bubble surface. However, the majority of the gas exchange caused by air stone aeration is actually because the bubbles break the water surface, which increases the surface area of the water surface and allows more oxygen to transfer from the atmosphere.

There are also various ways to test dissolved oxygen concentrations. Electrical meters with attached oxygen probes may be used, but these are usually very expensive and need to be calibrated regularly for reliable readings. There are also chemical "drip titration" oxygen tests, but these seem unreliable, complex and have low scale resolutions so give an approximate answer.

The best way to make sure dissolved oxygen concentrations are as high as possible is to use constant aeration to the areas of the system which require high dissolved oxygen concentrations. This is usually the fish tanks and the grow beds in deep flow (raft culture) systems.

Water Temperature

All of the organisms that live in aquaponic systems like a particular temperature range. I say temperature range because most things can live in a range of temperatures. What we need to do with an aquaponic system is find a balance between the temperature range requirements of all the organisms that live in the system.

Fish live in water and are dependent on the water temperature to set their internal temperature. There are a number of different species of fish that may be used in aquaponic systems. Mostly, these are fish that have adapted well to tank-based culture. In addition, there are different temperature requirements for different species of fish. For example, tropical species like *Tilapia spp*. like to live in temperatures of a range around approximately 27 ºC, whereas many Australian native fish like a range around 20 ºC.

Many fish can live in water temperatures outside of the range they are subject to in the wild. For example, I have kept Rainbow Trout at temperatures lower than, and higher than, their preferred temperature of approximately 12 ºC. Other fish are far less forgiving. Even though some fish will survive at temperatures outside of their normal range, this doesn't mean these temperatures are good for them.

As for other water chemistry parameters, fish do not like fast changes in water temperature. They can usually adapt to slow changes in water temperature, but if the water temperature changes by more than 1.5 – 2.0 ºC in less than 24 hours, then most fish suffer to some extent.

One of the first processes in fish that change in temperatures outside of their preferred range is feeding habit. Murray Cod (a native Australian species), for example, prefers temperatures between 18 ºC and 24 ºC, however, once temperatures fall below 16 ºC, they often stop eating. In an aquaponic context, if the fish stop feeding then no fish waste is produced and therefore, the nutrients required by the plants are limited.

For fish, it is always best to try and keep the water temperature near their preferred ideal water temperature.

Plants are similar to fish; some like warmer waters and some like cooler waters. Most of the plants we like to eat have undergone hundreds of years of farm-based adaptation to the surrounding temperature conditions. As many of the plants we eat have been adapted to European or North American farming practices, then most of them prefer water temperatures on the cooler side. A good target range for water temperatures for most plants is between 14 ºC and 22 ºC. However, as farming has traditionally occurred all over the world, there are always localised varieties that can grow outside of this range.

The bacteria and other micro-organisms that inhabit our aquaponic systems also have a preferred temperature range. For example, the nitrification bacteria that converts ammonia to nitrate like an average temperature of approximately 20 ºC. Outside of this temperature a drop in the conversion efficiency can be seen, and if water temperature is too far outside of this range then they can shut down completely.

Because many fish like an average temperature of approximately 20 ºC and the bacteria also like this temperature, and because this temperature is within the range that plants also like, a good temperature to aim for is about 20 ºC. However, as I have said, other water temperatures may be used as long as they match the fish, bacteria and plants being cultured. In addition, many plants and bacteria will adapt quite well to elevated water temperatures and this is why *Tilapia spp*. can be used successfully in aquaponics, even though the preferred water temperature is 27 ºC. Many plants and bacteria will adapt to this temperature.

As we all know, water temperature is tested with a thermometer. By tracking water temperatures we can see what may or may not happen in our systems and water temperature may be used as a management tool. For example, if water temperatures drop below 15 ºC when culturing Murray Cod, there is generally no point feeding them as they stop taking feed. The tracking of water temperature can allow us some forward planning in this sense. In addition, you would need to be careful feeding fish at this temperature anyway as the nitrification bacterial efficiency may have dropped and if the fish do take the feed, they may flood the system with un-processed ammonia that could have negative consequences.

Electrical Conductivity (EC)

The nutrients that plants take up are in the inorganic form. What this means is that plants will only take up nutrients that have been completely broken down to their basal form.

In aquatic systems, these inorganic nutrients are usually "charged" in some way. When these basal, inorganic nutrients are in aquatic systems, they exist as what is known as "ions". The ionic form of a nutrient is the charged form; the charges, like electricity, are either positive or negative.

Fish do release compounds that are quickly converted to, or immediately exist in, inorganic form, such as nitrogen (as ammonia) and phosphorous. These wastes (nutrients) are usually the ones that directly cross the fishes gills and are directly dissolved in the water. As we all know, even though fish release ammonia, it is quickly converted to nitrate in aquaponic systems. Plants will take up ammonia directly if required to, but they do prefer nitrogen in the nitrate form.

However, fish also release solid fish waste and this is made up of many organic compounds that form larger, uncharged molecules. Many people incorrectly believe that because fish release organic waste products that the plants will take up these organic compounds directly. This is rarely true, and many of these larger organic compounds must be first converted to smaller, charged or inorganic nutrients before plants can access them.

Interestingly, this is the same for soil; plants can only take up inorganic nutrients. Therefore, it doesn't matter whether you feed your plants fertilisers (inorganic fertiliser) or manures (organic fertilisers) as they all need to be converted to inorganic form for the plant to uptake them. So, if you are buying "organically certified" food, remember, those plants have only grown because the organic fertilisers have been converted by bacteria in the soil to inorganic forms.

The process of converting solid fish wastes, and the constituent larger, organic compounds, to the smaller, charged ionic nutrients is called mineralisation in aquaponics. It is the mineralisation bacteria that access and convert, the larger, organic compounds, to plant available, smaller and charged, inorganic nutrients. This process isn't just restricted to solid fish wastes, and fish do release other compounds in larger forms directly into the water column that require this conversion as well.

As we have seen, plants mainly access nutrients in an ionic or charged form. Electrical Conductivity (EC) measures the charges on these ions and gives a reading of how many charged ions are in the water. The more charged ions that are present in the water column, the higher the EC reading. However, it must be noted that EC only gives a total charged nutrient content in the water, and cannot distinguish between the different nutrient types.

Therefore, EC gives an indication of the total amount of plant available nutrient in the water column.

EC is measured in a few different units, such as Micro-semens per centimetre (µS/cm), Milli-semens per centimetre (mS/cm), and various EC units (usually used by the hydroponic industry and usually a direct metric conversion of the above two units).

EC works by directing an electrical charge through the water column. Electricity moves through a medium more easily, and faster, depending on the make-up of that medium. For example, electricity travels through seawater far easier than it does through freshwater because seawater has many more charged ions within it.

By passing a current through our aquaponic system water, we can take a measure of the "conductance" and this registers on a meter as an EC reading. The more inorganic, charged ions (nutrients) in the aquaponic system water, the higher the reading.

Therefore, EC may be used as a guide to the amount of inorganic, plant available nutrients within the aquaponic system.

EC may be used as a guide to the Total amount of nutrient in the system, but as I said before, it does not indicate the mixture of the nutrients or how much of each individual nutrient is present. If EC is to be used, this important aspect must be understood. For example, an initial EC reading may be taken and if the plants do not indicate any form of nutrient deficiency, then the reading may represent the total nutrient available. However, if the species of plant being grown is a heavy user of one particular nutrient, then a situation may arise where the EC reading stays the same, but the mixture of nutrients goes out of balance because the plant is removing more of one nutrient.

Because EC only gives a guide to total nutrient levels, it should be used with a full understanding of the above explained limitation.

EC is determined using an EC meter, which come in many different forms. Because EC meters simply send a current through the water column, they are often the most robust of any meter that may be purchased and used.

Conclusions

Water chemistry is a very complex science, and we have only touched on this complexity in this current fact sheet.

We have seen that the most important water chemistry parameter to test is pH, as this allows us to manage and manipulate the water chemistry to our own requirements. We have also seen that Dissolved Oxygen, Water Temperature and Electrical Conductivity are also important parameters that can allow us a certain amount of control, but more importantly, can be used as indicators of how our aquaponic systems are operating.

A Final Word

An understanding of water chemistry is paramount to controlled aquaponic system operation and management. I have only touched on the very basics of water chemistry in this fact sheet and this should cover what is required for most small, hobby-scale aquaponic systems. I would encourage anyone who is considering operating a commercial-scale aquaponic system to educate themselves to a

more in-depth level about water chemistry as it is a vital tool for commercial aquaponic system management and assists to avoid the number one issue with any technology or business; RISK!

Many excellent books are available on water chemistry, especially in aquaculture and hydroponics contexts. The best money you ever spend on your aquaponic system may just be the relatively small amount you spend on purchasing water chemistry texts test kits.

Happy Aquaponicing

Wilson Lennard
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