C. Organic Aquaponic System Water Chemistry

1. Measurement Methods

- **The things we measure in our water are: dissolved oxygen**, measured with a digital DO meter that costs about $350 and is really accurate; **nutrients** (ammonia, nitrites/nitrates) measured with different test strips you dip in and then read the color, that cost about $0.50 each; and **pH**, measured with a digital pH meter that costs $140. The basic measurement kit for a commercial aquaponics operation costs about $600, then about $200/year after that for the strips, which are consumable.

- **Check for iron deficiencies** by looking at the plants for new growth that is yellowish, which is a sign of iron deficiency. No one has invented a crud meter yet so we don't measure that. The water test form we use in included in the Appendices for this manual.

2. What We Measure In Our Systems, What It Means, And What To Add

Measuring DO (Dissolved Oxygen)

- **The most important water parameter we measure is DO** (dissolved oxygen), which we measure with a DO meter; the one we like is the Aquatic Ecosystems' catalog #850048 with a five-year warranty. If DO is 7, that's excellent. If it's 6 it's very good. If it's 5 it's decent. At 4 ppm you are OK but you should pay attention. If it's 3 you are stressing your fish. At 2 ppm you have an immediate problem and need to solve it within the next thirty minutes or less. At 1 ppm DO you are killing fish, they're just not floating yet. You'll notice there's a problem when they begin gasping at the surface after exertion (such as the feeding frenzy that happens when they are fed) and that's **not cute**, it's an indication that DO is low and your fish may be dying.

- **Get out your meter and find out what's going on**! You can get test strips for this also, but they cost $0.50 each, and that motivates you to test less rather than more often. You can do thousands of tests with your own DO meter, and the more often you use it, the less each test costs you. The DO meter is an essential tool for **frequently** monitoring the DO of the water coming into and going out of your troughs; this is an indication of how well things will grow in your system.

Measuring Ammonia, Nitrites, Nitrates, And Chlorine/Chloramine

- **To measure ammonia, nitrites/nitrates, and chlorine/chloramine,** we use simple commonly available test strips (brand names and suppliers are in the materials lists contained in the Construction Manual of this Training). They're easy to use: just dip them in the water for the length of time specified in their instructions, then compare the color of the strip to the colors on the bottle.

- **Ammonia is measured from 0 to 6 ppm** by the test strips. Above 6 is supposed to be toxic to the fish, but we think we had some of ours at much higher levels before we figured out how to fix it. Normal operating range for aquaponics systems is around .25 to 1.0 ppm ammonia. The same goes for nitrites: 6 ppm or over is toxic, normal operating range is .5 to 1.0 ppm. Nitrates are better tolerated by the fish, and operating range is 10-100 ppm, with toxic being between 500-1,000 ppm.

Ammonia and nitrite/nitrate test strips work just like these chlorine test strips: you dip them into the water, then compare the color on the pad to the color on the bottle to get your reading.

Nitrite/Nitrate tests are pink just like this chlorine test, and ammonia test strips start out yellow then turn darker green to indicate how much ammonia you have.

- **IMPORTANT!** If you are operating an organic aquaponics system (this means NOT using any caustic bases for pH adjusters), then your nitrite and nitrate levels **may appear so low** that only test strips with a sensitive range can even show them. The test strip we suggest is Hach AquaChek 27454, available from Aquatic EcoSystems catalog # H27454. This strip has a nitrite scale from 0.15 ppm up to 5 ppm, and a nitrate scale from 1 ppm up to 20 ppm. **If you use something else to test nitrites and nitrates, you MUST use a strip or test that can test at these levels of sensitivity, or you may think you have none!**

Measuring pH In Your Live Aquaponic System Water

- **We have started systems with water having a pH as high as 8.3** with no seeming ill effects, so don't worry about it. The pH starts trending downwards immediately as the fish breathe CO2 into the water and it transmutes into carbonic acid, lowering the pH. When the system pH is down around 6.2 or so, add calcium carbonate as mentioned in the section entitled **Nutrient and pH Levels,** and continue to monitor pH, adding calcium carbonate as necessary to buffer pH and bring it down.

  WARNING! **Do NOT** try to bring down a high pH caused by highly basic water or by having a poorly neutralized concrete tank in your system by using **citric acid**! Citric acid is an organic **herbicide**, and will kill your plant's roots. They all turn black, then the plants all die (courtesy of one of our students whose name we forgot!). We do not **yet** have a safe and approved method of bringing pH down, just buffering it up with calcium carbonate.

- **You can use the little pH test strips,** or the pH pad on a "multi-strip" to test pH in your system; but we've found that those are often quite inaccurate: they will often show as much as 1.0 off what the pH actually was (measured with a pH meter accurate to .01!). If you have a commercial-scale operation, you **should have** a good pH meter. The **VitalSine pH meter**, available from Aquatic EcoSystems for around $140, is the best one we've found. Despite the occasional bad review on the web, ours is rock-solid and dependable. In contrast, we got a Milwaukee pH meter for $245 that had great reviews, and it's never been able to measure pH or even stay calibrated for more than about 10 seconds.

A Vital Sine pH meter, about $140 from Aquatic EcoSystems.

Allowing the probe to dry out for more than fifteen minutes or so can damage or destroy the probe's accuracy. When you use it, take all your readings (this will keep the probe wet), then when you are done, store it in the plastic cap filled with storage fluid right away!

Storing the probe end in the plastic cap with storage fluid inside is critical!

- **When you buy the pH meter, you also need to buy** some pH calibration packets or fluid; this allows you to calibrate the meter so that you know your readings are accurate. **You also need to buy a quart** of pH electrode storage fluid; that is what you must keep inside the little screw-on cap on the probe. If the probe is out of the cap and dry for even a half hour, it can **destroy it. I've lost two $90 probes to employees** who didn't put the cap back on after using them.

- **We never leave the probe in a trough**, but put the meter and probe in our test kit basket in a safe dry place every time we finish with it (even though the meter claims to be waterproof). We calibrate it every time we use it by dipping it into a packet of 7.01 Milwaukee calibration/buffer solution I get from Aquatic EcoSystems (30 to a box), then we **know** the readings are accurate. We rinse the meter probe before putting it in the calibration packet to calibrate it, then carefully close the top of the buffer packet and stick a clothespin on it to hold it closed, storing it upright in a dry location, so we can re-use the calibration packet as many times as possible.

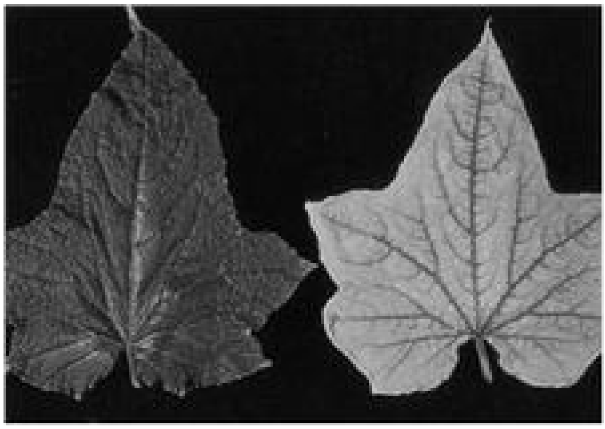
- **pH in these systems changes slowly**, and always towards the direction of acidification (lower pH numbers) so when we see a pH going down into the low 6-range we add a pound or two of calcium carbonate to the system to change the pH upwards towards 7, putting it in right where the water enters the first trough. Calcium carbonate is commonly found in the form of coral sand or crushed oyster shells. We've seen the systems be pH-stable for as long as a year and a half between additions.

- **You may be able to hurt your system** by adding too much at a time, but we think this would be difficult, as this carbonate tends to simply precipitate out of the system and lay on the bottoms of troughs or tanks when the pH gets to about 7. It then reabsorbs into the system when the pH goes down over time. When you make additions just do them a bit at a time instead of a barrel.

- **Warning!** Although we haven't run into it yet, a condition called "nutrient lockout" is caused in soil farming by too high or too low a pH level. If your pH is too high, nutrients such as iron, boron, magnesium, potassium and others become unavailable to the plants because of the interaction at the molecular level. This is called "nutrient lockout", and they really mean it, because it doesn't matter how much iron or other supplements you add if your pH is too high. At high enough pH's, the plants won't be able to access them, and will continue to exhibit symptoms of nutrient deficiencies although there is plenty of that specific nutrient in your system. Unfortunately, we can't give you a hard and fast number for what is too high. We DO know right around 7.0 is safe and productive.

Measuring Iron In Your Live Aquaponic System Water

- **We don't use an "iron test" to measure iron, we simply use our eyes and observe:** you have an iron deficiency when you see yellowish **new** growth on plants. Add iron to fix this. We add a pound or so of 13% organically certified iron chelate (Biomin brand is approved by the certifying agencies) each time we see yellow growth, usually about once every month or two. It's very satisfying: the plants green up sometimes within six hours or so of the iron going into the system. It takes us a year and a half to go through a 25-pound bag in our commercial operation with three systems.



This image shows an iron deficient leaf (on the right). A <u>nitrogen</u> deficient leaf looks exactly the same.

If your plants are iron deficient, <u>all</u> the leaves on the plant will look like this; if they are nitrogen deficient, <u>only</u> the largest, oldest leaves will look like this. That's how you tell them apart.

<u>3. Water Temperature, Aeration (DO), And Nutrient Levels In Organic Aquaponics Systems</u>

Water Temperature:

- **Fish move more slowly, eat less, use less oxygen, and metabolize less** at the lower end of their recommended temperature range (species-specific). Fish move faster, eat more, use more oxygen, and metabolize more at the upper end of this range. If your water is warmer, your fish will need more aeration; if it is colder, you will need less. **<u>IMPORTANT!</u>** This changes as the seasons change and the amount of fish in your tanks changes: keep taking measurements with your DO meter in Bboth troughs and fish tank to keep on top of it.

- **Water temperature influences something even more important:** the health and activity level of you nitrifying bacteria. Although the "experts" don't agree on the water temperature that nitrification activity is critically reduced at, they do agree that colder water results in less nitrifying activity on the part of your friendly bacteria. **This is critical to understand:** because it doesn't matter if your fish are fine in cold water if your nitrifiers slow down or stop their activity. You may get an ammonia buildup in your water and little to no "plant fertilizer" or nitrates; at which point your vegetable growth may slow or stop.

- **As a result, we recommend** operating with your system water temperature within the range of 70 to 80 degrees F if you are using a warm-water fish; and within the range of 60 to 70 degrees F if you are using a cold-water fish (and preferably near the 70-degree end of that range!).

Nutrient Levels:

- **Even though they never vary more than a few parts per million**, we still test measurable nutrient levels in our systems. **At least once a month!** The people who taught us in 2007 use highly caustic chemical pH adjusters in their systems to adjust pH swings (calcium hydroxide and potassium hydroxide, neither of which is organically certifiable). We feel these caustic chemicals artificially manipulate these systems into extreme measurable swings of nitrates, but **don't** actually provide more usable nutrients for the plants. We used these chemicals for the first few months until we went organic and started using an organically approved buffer chemical, calcium carbonate (coral beach sand). This is why we are so familiar with both these methods of adjusting pH.

- **During the few months we used the caustic chemicals**, we experienced the same pH swings the university documents in their literature, and had to adjust pH as often as every three weeks or so. When we switched over to organic buffering with calcium carbonate, we noticed that we only needed to adjust pH every four to six **months**; and that pH was rock-steady for months or even years at a time. We **also** noticed that the nitrate levels in the systems no longer had huge unexplained nervous swings, but were rock-steady at 1-3 ppm year-round, with an occasional HUGE jump to 10 ppm.

- **The hydroponics guys hate these numbers and tell us we're lying**; even the aquaponics "consultants" **claim that 60 ppm** is the minimum desired level for nitrates in aquaponics systems. Unfortunately, none of them can demonstrate a way to dependably and accurately adjust nutrient levels in their aquaponic systems.

- **This is because measurable nutrient levels** in an aquaponics system are the result of a complex arrangement that I don't believe they understand yet, let alone understand how to manipulate. We've been organically certified for six years and are just beginning to have a handle on it. We believe what was happening in the university systems when they adjusted pH with these highly caustic chemicals (hydroxides), was that each time they added them, they **killed off** the majority of their nitrifiers. What happened then is that they would get a **nitrite spike** when the nitrifiers **reestablished**, along with a **nitrate spike**, which accounts for the major swings in nitrate levels these systems experience.

- **The main reason for this conclusion** is that even in our **organic** systems, with **no hydroxides** present, we still see these swings. But they **only happen once** in the operating life of an **organic** aquaponic system, and that is **at system startup**. At system startup we will typically see a nitrite spike of up to 10 ppm for as long as two weeks or so, accompanied by nitrate levels of up to 40-160 ppm, lasting from two to six weeks after the nitrite spike is over. After this initial period of high nitrate levels, the system nitrates decrease to the previously mentioned 1-3 ppm and occasional 10 ppm, never varying out of this range in **years** of operation.

- **We are the only ones we're aware of** who have operated **both** the original university-type systems using the caustic pH adjusters, **and** our organic aquaponic systems using calcium carbonate as a pH buffer. These phenomena we've experienced have been in our water temperature range of 68-78° F. We don't have first-hand experience of this phenomenon in warmer water or colder water. We suspect you might have a higher range of nitrates in warmer water, and a lower range in colder water.

Nitrate Levels:

- **There is a lot of nonsense out there about "nitrate levels",** and what's "necessary for aquaponics". Many aquaponics "consultants" and others claim that 60 ppm is the **minimum** desired level for nitrates in aquaponics systems. In contradiction of their claims is the fact that **none** of them can demonstrate how to dependably or accurately **adjust** nitrate levels in their aquaponic systems.

- **That's because they <u>can't</u> adjust nitrate levels.** We've operated our systems for seven years now, and the "recommended method" of feeding more fish food just doesn't create more nitrates (even in our original university systems).

- **The whole discussion about what level of nitrates is necessary** seems silly to us, because we've successfully run systems with measurable nitrate levels of **zero** for months, experiencing explosive vegetable growth the whole time. Please see **Add Fish** in the **Startup Section** for more information on how much fish you need, and the fact that it's almost impossible to have a nitrogen (nitrate) deficiency outside of your startup period. What's **actually happening** in your system makes **total sense** compared to this nonsense discussion.

- **What's actually happening:** in a mature aquaponics system, you have a certain amount of area that your nitrifying bacteria can colonize, consisting of the roots of all the plants, plus any flat areas in the system such as sides and bottoms of fish tanks, undersides of rafts and sides of troughs. Can we agree on that? Good!

- **Even though there are zillions of bacteria**, and they've occupied all the possible surfaces in your system, there are still only **a certain number** of them; and their population is a number we can at least approximate limits for. Can we agree on that? OK, then it follows that a **limited** number of bacteria do not have an **unlimited ability** to process ammonia into nitrites and then into nitrates. Here's how this plays out in your **organic** aquaponics system:

- **We'll begin** with a normally operating **organic** aquaponics system that we use calcium carbonate in for adjusting pH. In such a system, your ammonia and nitrite levels will vary from 0.25 to 1 ppm; and your nitrate level will vary from 1 to 10 ppm (with occasional periods lasting months in which nitrates are not measurable at all, but the vegetables just keep growing explosively!). As your fish get bigger, it's tempting to feed them more, so you do. What you will notice at some point is that, as a result of feeding your fish more, and them generating more fish poop, your system ammonia level will begin rising (from its normal range of 0.25 to 1 ppm) up to 2 ppm, then 3 ppm, and so on.

- **This is happening** because your **limited** number of bacteria **do not** have an **unlimited ability** to process ammonia into nitrites and then into nitrates! When more ammonia shows up in the system than they can metabolize and convert, you have simply overwhelmed the ability of your bacteria to process ammonia and the ammonia level will continue to rise until you do something to stop it, such as **feeding your fish less**.

- **Although your system will work fine** with a very small amount of fish, if you have too many fish and/or feed them too much, your ammonia level will **rise**. Fortunately, there's a simple solution to this problem: **stop feeding them so much!** You can easily go from feeding your fish three times a day to once. If that doesn't do it, feed them once every other day. After a week to two of feeding the fish less, you will notice the ammonia level coming down from 3 ppm to 2, then to 1, which is where it should be.

- **The amount you feed the fish controls your ammonia level.** It is totally logical: more fish food in, more fish poop and ammonia out, regardless of the number of fish involved. They may get irritated if fed less, but it won't kill them; fish are not like people in this respect. We've omitted feeding our tilapia for up to three weeks at a time with no ill effects except they splash like crazy and soak the "feeder person" when they finally are fed!

- **When the situation becomes too extreme,** as when you are feeding your fish every third day, but the ammonia level is still rising, you need to **sell some fish**. Sell half of them and get them out of your system! Although you can't grow fish at a profit (you lose money, remember?), your fish will **still** get bigger and bigger until you have too many pounds of fish and too much ammonia. This is the indicator that it's time to sell fish; this creates cash flow too! Selling fish will help pay for the expense of raising them to be your "fertilizer generator".

- **There is one more thing you should know:** overfeeding the fish is **not** the only way to clobber your system with too much ammonia. If you have **any** other source of decaying organic material in your system, it will give off ammonia as part of the decay process. If your ammonia is rising quickly, look for dead stuff, such as a dead fish caught in a pipe, or a huge mass of roots or other vegetable material that a careless employee dumped into a trough instead of removing (see photo next).

It would have been easier just to leave this 100-pound wad of tomato roots in the trough when the tomato plants were removed, but they would have decayed and generated lots of ammonia that would negatively affect the system's operation.

Remove any "stray" sources of ammonia such as this from your system as soon as you become aware of them!

How Can It Possibly Work? (Rather, If It Works, How Can You Argue With It?)

- **As we mentioned earlier,** in a normal **organic** aquaponics system, your nitrate level will vary from 1 to 10 ppm (with occasional periods lasting months in which nitrates are not measurable **at all**, but the vegetables just keep growing explosively!). The **only** time we ever see nitrite or nitrate measurements higher than these in an organic aquaponic system is during system startup (in the **Startup** section of the manual, next). This fact piqued our interest, and helped us develop our current hypothesis, which may explain the difference between nutrient levels in our organic systems and in chemical-based systems (how we refer to systems that use hydroxides for pH adjusters).

- **We think the chemical-based systems** show these higher levels of nitrites and nitrates because the repeating applications of caustic chemicals used in them cause repeating die-offs of nitrifying bacteria, which then re-establish themselves in a cycle similar to that which produces the nitrite and nitrate spikes one sees during a normal aquaponic system startup.

- **The important thing about seeing these operating nutrient** levels in organic aquaponics is that it throws much of the conventional wisdom out the window. We **don't know** exactly what's happening in our systems. We would love to have a spectrometer, a lab, a year or two, and about $120,000 in salaries and costs for lab workers to get a good handle on what the actual processes are at a microbiological level. What we **do** understand is that the systems keep growing stuff like crazy even though nitrates are barely measurable (or **zero**), and they feed us.

- **And because to be human** is to want at least an outline of an explanation of things, here's what we've come up with as a **working hypothesis** to explain this behavior: **the fish are in the system and eating and pooping**, so there is decaying organic matter in the water that is passing into the hydroponics troughs. The vegetables are still growing **just fine**, so they **must** be getting nutrients **from somewhere**. We think it starts with the small, suspended bits of decaying organic material (fish poop) that are circulating through the system constantly, and constantly getting turned into **ammonia** by the system bacteria and chemical processes that do that job.

- **Next, the bacteria on each root** metabolize the ammonia in the system water (that is constantly passing by them) into nitrites and then nitrates, **right on the surface of the root itself**. The roots then immediately absorb the nutrients. There are no measurable nutrients in the system water because all this activity is taking place in the few thousandths of an inch of microcosm around the roots of the plants.

- **When we stick a test strip** into the water to measure nitrates, it is **miles away** (on a bacterial scale) from the bacteria on the root that are **making** the nitrates. So of course we measure low or nonexistent nitrate readings in systems that are growing vegetables like crazy! We don't know of a way to measure the production of nitrates on a root without an expensive lab and the correct experimental protocols. "Zero nitrates" is **not** a problem in organic aquaponics systems.

4. Additions (And Things To NOT Add!)

- **The only things we add** to our systems besides fish food are: **iron chelate** and **calcium carbonate** (also covered in **What We Measure, What It Means, And What To Add**). One of these chemicals provides valuable additional iron, and the other provides calcium to the plants in the system, in addition to adjusting the pH. We add by mixing them in a 5-gallon bucket and dumping the bucket into the first trough in your trough series where the water flows in.

- **WARNING!** The university uses potassium hydroxide and calcium hydroxide as system additions, which are both highly caustic chemicals. They also use an additions tank that lets this stuff into the system **slowly**. **If** you use these chemicals (and we do **not** recommend they be used), be aware that they are **not** organically certifiable, and that using them may **preclude** the possibility of certification, they **do** need to be handled with proper safety precautions and protective clothing, gloves, and eyewear, and they **do** need to be trickled slowly into the system to avoid killing fish and plants with a burst of highly caustic basic water. Your pH and nutrient levels may also experience large unexplainable swings when you use these chemicals for adjusting pH.

- **WARNING!** Our students have "tried out" several other kinds of additives for various reasons of their own. We usually hear about this after their plants are dying or sick, and are asked to come up with a solution to the problem. There is nothing **wrong** with trying out new things in your aquaponic system; just make certain that it is a system that you are willing to sacrifice for the new knowledge you intend to gain in the process. Like a nice small TableTop system!