The Chemistry and Microbiology of Aquaponics

HCPS III Benchmarks

SC.6.1.2 Use appropriate tools, equipment, and techniques safely to collect, display, and analyze data
SC.6.2.1 Explain how technology has an impact on society and science
SC.6.2.2 Explain how the needs of society have influenced the development and use of technologies
SC.6.6.5 Explain how matter can change physical or chemical forms, but the total amount of matter remains constant
SC.6.6.6 Describe and compare the physical and chemical properties of different substances
SC.6.6.8 Recognize changes that indicate that a chemical reaction has taken place
SC.7.3.2 Explain the interaction and dependence of organisms on one another
SC.7.3.3 Explain how biotic and abiotic factors affect the carrying capacity and sustainability of an ecosystem

National Science Education Standards

Systems, order, and organization
Change, constancy, and measurement
Properties and changes of properties in matter
Motions and forces
Structure and function in living systems
Populations and ecosystems
Abilities of technological design
Science and technology in society
Science as a human endeavor
History of Science

TIME: 45 minutes

Background

This lesson is designed to utilize aquaponics setups as a means to teach chemistry and microbiology. Keep in mind that aquaponics is a developing science and that the various parameters of water quality are guidelines. When maintaining your aquaponics system it is important that there is balance between the number of fish and plants, ammonia, nitrites and nitrates, oxygenation of water, pH, carbon dioxide, and temperature and free of pathogens. Utilizing the scientific method will allow you to record and track data to develop a better understanding of the workings of your aquaponics system.

Chlorine and Chloramines

If you are starting a brand new setup and using municipal (tap) water you will want to find out a little bit about your water. Most municipal water in Hawaii is treated with chlorine to disinfect any potential harmful microbial contaminants, i.e. pathogens. Although

chlorine (Cl_2) is toxic to fish, it is a gas, which will evaporate when water is left to stand. To make sure that all chlorine is evaporated, let the water sit out for at least a day or two while exposed to sunlight. A pump that agitates the surface of the water will speed up the process by increasing circulation and exposing the chlorine to the surface where it will evaporate. (Option: a chlorine test to monitor the initial and final chlorine levels will verify whether all the chlorine has dissapated, although this is not required)

Chloramine is a compound that is being increasingly used to treat water in other parts of the country partly because it does not outgas and therefore remains in the water as an effective disinfectant. Only a few places in Hawaii are served with water treated with chloramine, such as by the Olinda Water Treatment Facility that supplies water for upper Kula in Maui. Because chloramine (NH_2Cl) does not evaporate, it will need to be removed by another means. Chloramine may be removed via filtration with activated carbon (removes chlorine) and zeolite (removes ammonia), adding 1000mg food grade ascorbic acid (vitamin C) to 40 gal of tap water, or by adding an aquarium water detoxifier such as AmQuel (sodium hydroxymethanesulfonate) according to the manufacturer's instructions.

http://chloramine.org/articles_pdf/Chemicals_in_Drinking_Water_Chloramines.pdf

To find out if your water is treated with chlorine or chloramine you should check your water bill or your Annual Water Quality Report sent out each year around July 1st as mandated by the Environmental Protection Agency (EPA). You may also go to Board of Water Supply's website link to download the water quality report and enter your address at the following link: http://www.hbws.org/cssweb/display.cfm?sid=1081 . If your water is not supplied by the Board of Water Supply you will want to contact the providers listed on your water bill to find out more information about how your water is treated.

Activity

Materials

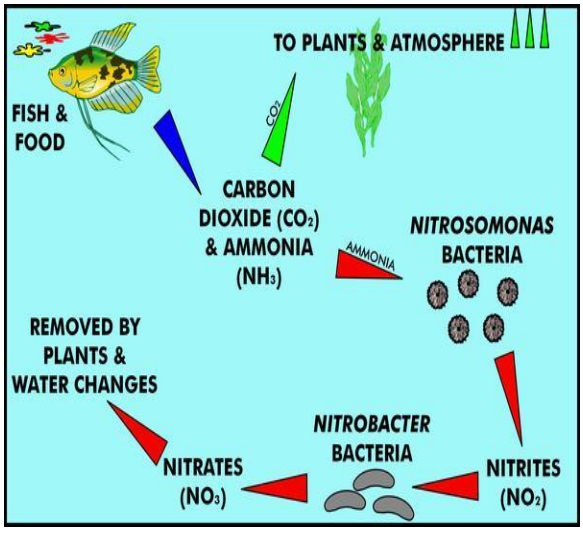
Chlorine test kit available at: http://www.ctahr.hawaii.edu/hawaiirain/test.html

Follow instructions of test kit. Test before and after you have removed the chlorine in your water to make sure that all chlorine has been removed.

The Nitrogen Cycle

According to Australian aquaculturalist Dr. Wilson Lennard, the most important life forms in an aquaponics system are the microbes, which are principally bacteria, but also include fungi, algae, zooplankton, and phytoplankton. These microbes process the fish waste, including dissolved and non-dissolved solids. The end products

processed by these microorganisms become non-toxic to fish and available to plants as nutrients. The principal waste products from fish are organic, nitrogen containing materials including proteins, amino acids, and ammonia (NH_4). Most microbes are able to convert the larger nitrogen containing waste products of protein and amino acids into ammonia. This process is referred to as ammonification, also called mineralization, and basically breaks down solid waste until it can be dissolved into the water.



When ammonia is produced, the nitrifying bacteria come into play. Certain bacteria such as the Nitrosomonas are called nitrifying bacteria because they convert the ammonia into nitrites (NO_2^-). Nitrites, however are still toxic to fish and not readily used by plants. Nitrobacter are bacteria that converts nitrite into nitrate (NO_3^-) a form that is both non-toxic to fish and the preferred form of nitrogen for plant roots. The nitrification process requires oxygen (O2) and is one of the reasons that water must be properly oxygenated. In addition, fish breathe oxygen from the water, and plant roots use them as well. For this reason it is important to have constant water circulation in all parts of the system to prevent the buildup of ammonia and creating oxygen depleted areas.

Generally it is said that you should feed fish twice per day and only what they eat in 5-10 minutes. Otherwise the fish feed may disintegrate and will be a source of excess ammonia from the breakdown of this solid organic material. A general guideline from aquaculturalist Jim Rakocy for plant nutrient requirements is that you should give 60 g fish feed/ m^2 of plant growing area per day for leafy greens and up to 100 g fish feed/ m^2 of plant growing area for fruits.

To ensure that your system is functioning properly you will want to test ammonia, nitrite, and nitrate levels. If your ammonia levels are too high you may be feeding your fish too much. See below for a rough guideline to toxicity of ammonia at varying temperatures and pH. Note that as temperature and pH increase, so does the toxicity of ammonia.

When you start a new aquaponics setup it is suggested to start by cycling your water for a several days without fish to form a healthy colony of nitrifying bacteria without stressing the fish. It is suggested that dosing the setup with an ammonia concentration of 2 parts per million is sufficient. 1 part per million (ppm) is equivalent to 1 ml/ 1000 L (about 264 gallons). You may

then test the levels of ammonia with your test kit until ammonia levels have dropped to a safe level (see chart below). You should also note that as ammonia levels drop, nitrite levels rise and fall, then nitrate levels should increase, which is the desired outcome. Special inoculants may also be used to jumpstart your setup although it is not necessary. You may start with plants in your setup during the cycling phase since ammonia is less toxic for plants. You may also wish to track the ammonia per day and graph or keep a log of your results.

It is then suggested that you stock your tank at partial capacity for the first week or so, again to check the health of the system. Then you may stock your system to capacity. Maximum recommended densities range from 1 fish per 3 gal of water to 1 fish per 6 gallons of water, although these are just guidelines. Preferences will vary among fish species.

Total Ammonia Nitrogen (TAN) - ppm
Use this table to find out when ammonia levels will start to become toxic to your fish

Temp (°C)	pH 6.0	6.4	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4
4	200	67	29	18	11	7.1	4.4	2.8	1.8	1.1	0.68
8	100	50	20	13	8.0	5.1	3.2	2.0	1.3	0.83	0.5
12	100	40	14	9.5	5.9	3.7	2.4	1.5	0.95	.61	0.36
16	67	29	11	6.9	4.4	2.7	1.8	1.1	0.71	0.45	0.27
20	50	20	8.0	5.1	3.2	2.1	1.3	0.83	0.53	0.34	0.21
24	40	15	6.1	3.9	2.4	1.5	0.98	0.63	0.4	0.26	0.16
28	29	12	4.7	2.9	1.8	1.2	0.75	0.48	0.31	0.2	0.12
32	22	8.7	3.5	2.2	1.4	0.89	0.57	0.37	0.24	0.16	0.1

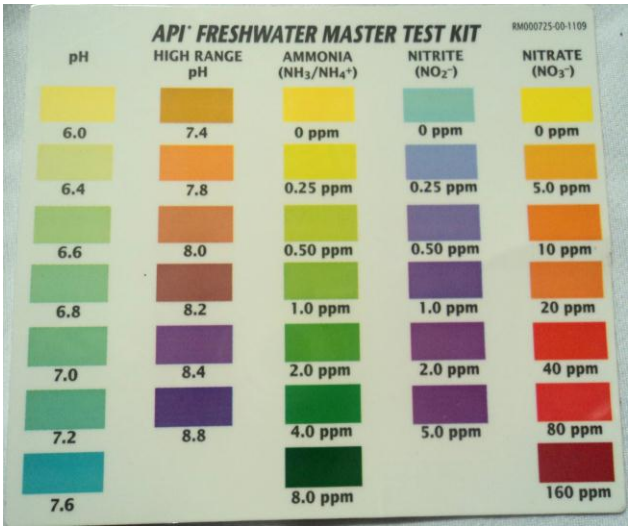
Activity: test nitrates, nitrites, and ammonia

Sloss,Watters, School Garden Curriculum

Materials

API Master Freshwater testing kit or equivalent

Detailed instructions are given with test kits on how to test for various nitrogen containing compounds. You may want to track the values of ammonia, nitrates, and nitrites on a continual basis and graph the results. Record observations noted on the health of various plants and fish if noticeable.



Oxygenation

To ensure proper oxygenation make sure that there is adequate water flow. Generally it is recommended to get a pump that will displace the entire volume of water at least every hour. If the pump is on for example a 15 minute timer, then the pump should displace the entire volume of water in 15 minutes. In nature, oxygen is mixed into water through the natural patterns of tumbling

down streams, waterfalls, and via wave action. Plant roots and certain algae are able to oxygenate water as well as a by product of photosynthesis (see lesson 6). In general cooler water is able to hold more dissolved oxygen than warmer water.

One method of mimicking nature to increase oxygenation often utilized in aquaponics is the drip flow method. This method drips the recycled clean water from the plant bed back into the fish tank creating a waterfall effect. Another technique is to make sure that the plant growth media is completely drained each cycle with no stagnant water left in the system. This will ensure that the all of the surface area of the growth media will be exposed to air, allowing the nitrifying bacteria to consume additional oxygen at the bottom of the media.

Check with your local aquarium and/or tack and feed store to see if pumps are available. Fish require a minimum concentration of 4 mg/L dissolved oxygen. 10 mg/L is about the highest oxygenation levels you will be able to achieve at normal conditions. For complete steps to monitor dissolved oxygen via drip titration (more appropriate for highschool chemistry students), see the following link: http://www.indiana.edu/~bradwood/eagles/dot.htm

Activity: test water for Oxygenation

Materials

Tetra test kit - around $10at the following website http://www.aquariumguys.com/oxygen-test-kits.html or may be found at an aquarium store. An oxygen meter may also be used for constant monitoring but can be costly.

Aquaponics setup utilizing the waterfall effect to enhance oxygenation. The Gravel bed is the biofilter and contains live worms that aid in breakdown of solids

pH

PH is also referred to as the "Power of Hydrogen". It refers to the concentration of hydrogen ions (H^+) in solution which determines the acidity or alkalinity of the solution. The pH scale goes from 0 to 14 with zero being

extremely acidic and 14 extremely basic or alkaline. A pH of 7 is said to be neutral and is generally around where drinking water should be. Fish and humans have a similar blood pH of around 7.4, thus it is not surprising that we both prefer water close to neutral. Many fish including tilapia and catfish will tolerate a pH range of 6-8. Plants however tend to prefer a lower pH of around 5-7 where nutrient availability is greatest. A compromise that many aquaculturalists use in aquaponics is to shoot for a pH range of 6.4 – 6.8. However many people will attest that aquaponics funtions best at a pH even lower, some as low as 5.5.

Activity: Monitor your pH

Materials

API Freshwater Master Test Kit or equivalent

Follow instructions given to test for pH. Remember the kit includes one for basic solutions and one for acidic solutions. Make sure you are using the appropriate test. Track your pH over a period of three weeks every other day at the start of your setup and once a week thereafter. You may wish to graph your results and compare plant growth with pH of the water.

Temperature

Temperature requirements for aquacultured fish are very species dependent, so it is important to know the temperature preferences of the fish you are culturing If for any reason your aquaponics setup falls outside of this temperature range you should stop feeding and work to get your temperature within normal range. Fish that are either too hot or too cold will become stressed and will not eat. Adding food to the system when fish are not eating will add to the ammonification and further stress the fish.

Temperature can be monitored with a regular thermometer. A mercury thermometer is not recommended as it could break and leak mercury into the system. It is recommended that a thermometer be constantly submerged and that temperature tracking is a regular practice. Generally, Hawaii's lower elevations do not undergo wide temperature fluctuations. However, at higher elevations, larger temperature fluctuations can occur, which is a great stress to the fish. Water may also become too hot if tank is not shaded. Some individuals using well water may have water that is cold for some warmer fish species like tilapia, which prefer a temperature range of around 26°C - 30°C. Note on the chart above that as temperature increases so does the toxicity of both increasing ammonia levels and increasing pH.

Activity: Monitor temperature changes

Materials

Standard thermometer (non-mercury containing)

Measure the initial temperature of your water to make sure it is within an acceptable range for the fish you are culturing. Remember tilapia are tropical fish and prefer a warmer temperature of 26°C - 30°C. You may want to measure temperature first thing in the morning and late in the afternoon to track for large temperature swings. If you notice your setup getting too hot or too cold, you may want to make adjustments to your system. For example, if the water is too cold in the morning you may want to paint the outside black to absorb more heat. If the water is too hot during the afternoon you will want to shade and/or paint your container white.

Reference:

Lecture given by Dr. Wilson Lennard at the Hawaii Aquaculture and Aquaponics Association (HAAA) annual meeting in Hilo, HI on August 11, 2010.

Lecture given by Dr. Jim Rakocy at the Hawaii Aquaculture and Aquaponics (HAAA) annual meeting in Hilo, HI on August 11, 2010.

http://www.ecofilms.com.au/2010/08/04/aquaponics-health-understanding-Sloss,Watters, School Garden Curriculum

ammonia-water-temperature-and-ph-balance/

Water testing resources:
http://www.ctahr.hawaii.edu/hawaiirain/test.html

Resources for setting up your own aquaponics garden in school:

http://www.ctahr.hawaii.edu/oc/freepubs/pdf/SA-2.pdf
http://www.ctahr.hawaii.edu/oc/freepubs/pdf/BIO-10.pdf
http://www.aquaculturehub.org/group/aquaponics
http://www.ctahr.hawaii.edu/oc/freepubs/pdf/FST-38.pdf
http://www.friendlyaquaponics.com/
http://www.backyardaquaponics.com/
www.aquaculturehub.org