The Chemistry of Aquaponics

Adapted from the Texas Aquaponic Guide

Contents

THE CHEMISTRY OF AQUAPONICS

The chemistry of your Aquaponic water is one of the most important factors to Aquaponic success. Many factors can influence a healthy water balance.

They may include:

- Number of fish (ammonia)
- Stage of cycling (nitrites)
- Temperature (oxygen)
- Alkalinity (pH)
- Fish food (Iron/Potassium deficiency)
- Water supply (Chlorine)

This publication is designed to give you a high level overview of potential chemical threats to your Aquaponic system. For a more in-depth study of all Aquaponic aspects, consult The Texas Aquaponic Guide.

Water Chemistry

The water in your Aquaponic system should always appear clean to the degree that there isn't an excessive amount of solid debris suspended or lingering on the bottom. Suspended particles can add to the addition of ammonia, thus altering the pH. Air bubbles should appear crisp and pop relatively quickly. If air bubbles linger too long before they "pop", it is an indication of a bacteria problem. What causes a bacteria problem? Among other things, they may be dying from a chemical imbalance in the water.

Learn to listen to the system. If you walk up to your fish tank and there is no sound of bubbles, something is wrong. You may still hear the air pump, but the tubing may have slipped off the pump. This will cause a dissolved oxygen (DO) problem. Perhaps the air pump became unplugged but yet you still hear the sound of the water flowing out of your plant trough via the water pump. When it comes to air, you have very little time before your fish are damaged due to lack of oxygen.

A properly cycled Aquaponic system should never smell bad. In fact, when properly cycled and in balance, it should smell fresh and clean. A bad odor usually means there are dead fish in the system, or there is a bacteria problem. Check the system for obvious problems, and then test the water to determine the best course of action.

Fish Chemistry

Fish excrete ammonia which is toxic to themselves, the bacteria, and plants. The more fish that are in your system relative to your water volume affect the chemical balance in terms of ammonia. In large bodies of water, this is not a problem because of dilution. But in an enclosed tank, this accumulates quickly and becomes deadly. Excess ammonia can cause tissue damage to fish's gills and kidneys, impair their resistance to diseases, and stunt growth.

Also affected in an Aquaponic system, are the bacteria and plants. The only practical way to reduce a sudden "spike" in ammonia and nitrites (a nitrite spike) is to do a partial water change. A standard water change involves dumping and replacing one third of the water volume with clean, off gassed water.

You must never over feed the fish as this will also result in the production of more ammonia and possibly clog your water pump.

Bacteria Chemistry

Watching the air bubbles can be a good indicator of a bacteria problem, which may have resulted from excess ammonia and nitrites in the water. Under normal healthy conditions, air bubbles form quickly, move quickly above the surface of the water, and then pop. When the Aquaponic water appears thick, and bubbles are sluggish and lingering, this is an indication of a potential bacteria problem. Imagine a swamp. You may see a difference in your fish's behavior due to increased stress. Outside of an occasional dead fish, any bad odor can usually be attributed to a bacteria problem. Test the water and determine the best course of action.

Plant Chemistry

Though sounds and smells don't generally relate to plants, they are the most visible. Depending upon what you are growing, your plants should look healthy and vibrant in an Aquaponic system. Depending upon the fish food you are using, the primary nutrient deficiencies will probably be Iron, Potassium, and Calcium. A stressed plant may exhibit discoloration (chlorosis), obvious stress, or outright death when the system is out of balance. Fruits may be stagnated or not flourish after flowering. These are all longer term symptoms of the system being out of balance.

Testing

Testing is an integral part of Aquaponics. There are myriad things to consider when it comes to overall system health, and many involve testing of some sort. Testing your system is imperative, especially during the cycling phase. Water testing equipment generally comes in three forms – test strips, reagents (liquids), and electronic equipment.

Test strips have various test pads on a plastic strip and when dipped in the water, change color according to outcome of the test. Generally test strips include tests for Nitrites, Nitrates, Chlorine, pH, Alkalinity, and Hardness.

Reagents are liquids that are mixed with the water. Sometimes two different solutions are used and the test results are determined by the water's color after mixing.

Electronic testing equipment can get expensive and is limited to only a few tests involving Aquaponics. Some available tests are pH, Dissolved Oxygen, and Temperature.

Monitoring the System - Sights, Sounds, and Smells

Not all testing comes from a test kit. Learn to use your senses first and foremost.

Over time, and by being observant, you will get to know your Aquaponic system. There are three separate ecosystems existing within the system, each with different characteristics and needs. There are several tasks which you should become familiar with, so that they will become automatic every time you approach your system. Think of running your car. You wouldn't normally do an analysis every time you start it, but if something sounds off; you will probably realize it pretty quickly.

pH Balance

Because plants prefer a pH of about 6.0 and fish prefer a pH of 8.0, it is common in Aquaponics to compromise and try to keep the system neutral at

7.0. This range satisfies the fish, plants and bacteria. The pH of the system can be raised or lowered depending upon the need. Be certain never to add anything to the system without diluting the substance. That is, dilute the substance in a bucket and add it to the plant trough slowly. When lowering the pH, add the water over the course of the day or so.

NOTE: If you have a media bed and the media contains limestone, it will be extremely difficult to get the pH down. You should get different media that is not reactive such as river rock, granite, or expanded clay.

Raising pH

Normal nitrification has a tendency to reduce pH (make more acidic). There is usually the opposite problem in many parts of Texas due to the large amount of limestone in the substrate. But if your Aquaponic water is acidic, this can be kept in check by adding a safe alkaline substance such as calcium carbonate (CaC03). Calcium carbonate increases pH, but stops dissolving at a pH of around 7.4, meaning pH will stay pretty stable until all of the available calcium carbonate is depleted.

Other sources of calcium carbonate include:

- limestone
- shell grit
- seashells
- egg shells

Lowering pH

Aquaponic systems tend to be acidic, but in many parts of Texas, the limestone substrate tends to keep our water alkaline (high pH). Hydrochloric or muriatic acid is commonly used to reduce pH levels. Vinegar and lemon juice can also be used in a pinch, but are not as effective as these acids and not recommended in large quatities. Do not use sulfuric or citric acid. The right quantity of acid to be used is dependent on the buffering capacity of the water. Add a small bit to a five gallon bucket of preferably clean dechlorinated water, and mix well. Add it slowly to the plant trough. Wait for about a day and check the pH the next day and continue if necessary.

pH should be adjusted slowly.

Some things to know about pH

The pH scale runs from 0 to 14, with 7 being neutral (neither acid nor alkaline). That is, values below 7 are acid and above are alkaline. The pH scale is logarithmic. So as the pH moves away from 7, each step up or down is 10 times stronger than the last. In other words, a pH 6 is 10 times and a pH 5 is 100 times more acidic than pH 7. This is why a pH swing of just a couple of units can seriously affect fish and bacteria health and function.

When dissolved in water, carbon dioxide is acidic. Fish generate carbon dioxide day and night. This is why in a system that is not adequately buffered, the pH tends to be lower in the morning then at night. Keep this in mind when testing for pH.

• The optimum pH range for Nitrosomonas (converts ammonia to nitrites) is 7.8 - 8.0

• The optimum pH range for Nitrobacter (converts nitrites to nitrates) is 7.3 - 7.5

• At a pH below 7.0, Nitrosomonas growth slows and an increase in ammonia may become apparent

• At pH 6.5, Nitrosomonas growth is greatly inhibited

• At a pH below 6.0, all nitrification is inhibited

NOTE: That last bullet point, a pH below 6.0 all nitrification is inhibited, was determined in a sterile lab culture. Other research indicates that certain species of Nitrosomonas in a natural environment such a pond will still process ammonia even at pH 4.0. This helps explain why some Aquaponic systems that have operated for years with a pH of 6.0, have no ammonia, and happy fish. Go figure!

Like temperature, suitable pH range varies with different fish species. A pH level that is outside of the preferred range will have a negative affect on fish health. Damage to the fish's slime coat will make them more prone to disease. Respiratory issues may also result due to the pH affecting gill function.

It is important to keep your tank within a healthy range and to avoid major fluctuations within this range over short periods. Fluctuations will stress your fish and could result in death or increased susceptibility to disease. Although the suitable range will vary between species, most freshwater fish can be permanently kept at pH within the range 5.5 to 8.0 and many have a wider range. These ranges of course, are not the same for plants and will affect bacterial processing.

Ammonia (TAN)

There are two primary sources of ammonia in an Aquaponic system. The first is excreted by the fish from their gills and waste. The second is produced through natural biological conversion of decaying organic matter (such as uneaten fish food), and dead plant matter within the grow-beds (old plant roots).

Ammonia exists in two forms, ionized and un-ionized. As temperature and pH increase, so does the percent of total ammonia that exists in the un-ionized form. It is un-ionized ammonia that is most toxic to fish because of its ability to be absorbed by the fish across their gills. Ionized ammonia is only harmful in high concentrations and is not likely to be an issue in an Aquaponics system.

Most test kits do not differentiate between these two forms of ammonia, but instead give a measurement that represents the total ammonia nitrogen (TAN), which consists of both ionized and un-ionized ammonia. Generally, normal tests for ammonia are close enough to the true levels to alert you to any unhealthy conditions.

Nitrites

Nitrites affect the ability of the fish's gills to efficiently transfer oxygen to bloodstream. At rates as low as 0.5 ppm, nitrites can be harmful to your fish. This is why managing a nitrite spike_during cycling is so critical. This becomes even more significant when oxygen levels in the water are lower, for example from higher temperatures. When cycling your system and the nitrite levels elevate, what is really happening is that your first nitrifying bacteria, Nitrosomonas, is breaking down the ammonia in the water. But, the second nitrifying bacteria, Nitrobacter has not yet populated to significant numbers to process the nitrites into nitrates.

WHEN NITRITES ARE HIGH, STOP FEEDING YOUR FISH!

Other factors that may affect elevated nitrite levels are too many fish for your size system, overfeeding, under-developed bacteria for the amount of ammonia being produced, large amounts of decaying matter in the plant troughs, or sunlight hitting the water which kills beneficial nitrifying bacteria.

Nitrates

Nitrates are not harmful to fish unless in very high quantities. Since it is the plants that absorb the nitrates in an Aquaponic system, there must be an adequate number of plants to balance the production. This is proportional to the system size and number of fish (weight), and feeding ratio.

Some things to know about Nitrifying Bacteria

- Optimum growth ranges for nitrifying bacteria is between 77° - 86°F.
- The rate of growth decreases by 50% at 64° F
- The rate of growth decreases by 75% at 46° - 50° F
- No activity will occur at 39°F
- Nitrifying bacteria will die at 32°F
- Nitrifying bacteria will die at 120°F
- Nitrobacter is less tolerant of low temperatures than Nitrosomonas.
- In cold water systems, care must be taken to monitor the accumulation of nitrites

Alkalinity and Hardness

Alkalinity and hardness are important in Aquaponics and a big issue in Texas water. But not to worry, it is by no means a show stopper, more an inconvenience. To a large degree, these two factors regulate the cushion (buffering) power of water to resist pH change. If the water has a higher alkalinity, it is more resistant to pH changes. This is important to the fish, plants and bacteria. To truly understand alkalinity and hardness requires some knowledge of chemistry such as ions, molar concentrations, anions, and buffering, which is beyond the scope of this publication. But following is a high level overview of water alkalinity and hardness as it applies to Aquaponics.

Alkalinity

Alkalinity is the capacity of water to neutralize acids without increasing the pH. In other words, total alkalinity is water's capacity to absorb acids. Thus, water with high alkalinity is able to absorb more acid. The basic ions include bicarbonate (HCO3), carbonate (CO32), and hydroxide (OH). In Aquaponics, moderate levels of bicarbonate, and carbonate ions are beneficial for fish. Alkalinity is important in Aquaponics to offset the normal buildup of carbon dioxide, which is a source for acid formation. These formations come from normal respiration and bacterial processes which can cause the pH to drop rapidly.

Specifically, if the water is sufficiently alkaline, excess acid is converted by the carbonate ions and the pH remains stable. This is why it is important to choose your media wisely, if a media bed is what you have. You must take this into account with your water source. Texas groundwater tends to be very alkaline due to the limestone substrate, while rainwater tends to be acidic, which of course would help offset this imbalance. A neutral media such as expanded clay beads or river rock will have no affect on the pH. Limestone rocks or some other like material will tend to raise the alkalinity level of the water way beyond neutral.

Hardness

Water hardness is similar to alkalinity but represents a measure of calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}), and other ions for aluminum, iron, manganese, and/or zinc. In Texas, there are two primary types of water hardness: general hardness (GH) and carbonate hardness (KH), also known as alkalinity. There is also another called total hardness, which is a combination of GH and KH. Most test kits test for total hardness, which can be misleading. Both GH and KH are important to know, so it is best to test for hardness values individually.

General Hardness

For Aquaponic purposes, GH is a measure of the calcium (Ca^{++}) and magnesium (Mg^{++}) ions in the water. This does not directly affect pH, but when water is hard, it is usually alkaline due to the interactions between GH and KH. Water hardness is measured in ppm of calcium carbonate ($CaC0_3$) and that can be a problem, because test kits generally tend to test for hardness using, as said, the ppm of $CaC0_3$ in the water. This means the test does not take into account that the hardness may have come from another source other than $CaCo_3$, so the readings may be erroneous.

Optimal hardness for Aquaponic water ranges from 100-300 ppm $CaC0_3$.

General Hardness (GH) Guidelines:

0 – 75 ppm...Soft

75 – 150 ppm...Medium Hard

150 - 300 ppm..Hard

300 + ppm..Very Hard

GH is the more important of the two types of hardness when it comes to biological processes. In Aquaponics, general hardness is relevant to the degree to which it affects fish which may prefer either "hard" or "soft" water environments (or somewhere in between). If GH is out of balance for a particular fish species, it can affect the transfer of nutrients and waste products through the fish's cell membranes which in turn cause other issues such as stunted growth, internal organ malfunctions, and infertility.

Carbonate Hardness

Carbonate hardness (KH), is the measure of bicarbonate (HCO_3) and carbonate (CO_3^{2-}) ions in the water. With carbonate hardness, terms such as acid binding, acid buffering capacity, and alkalinity are used interchangeably. In an Aquaponic system, KH acts as a chemical buffering agent, helping to stabilize pH. KH is generally referred to in degrees of hardness and is expressed in $CaCO_3$ equivalents just like GH. This means hardness is measured in terms of how much calcium carbonate is dissolved in the water.

Chlorine, Off-Gassing, and Chloramines

Before adding bacteria or fish to your Aquaponic system, all chlorine must be completely "off-gassed".

Off-gassing can be accomplished by letting the water sit for a few days or by aerating it over night, using an air pump, in a 5 gallon (or so) bucket. If you are off-gassing a 300 gallon tank or any increment of this volume, aerate the water for 3-5 days, then test for chlorine. The longer the chlorinated water bubbles using air stones, the more successful your cycling and water change efforts will be as this process also oxygenates the water.

Unfortunately almost all water municipalities now treat drinking water with chloramines. Chloramines are more stable than chlorine, which is a gas and thus can be 'off-gassed". With chloramines it is different. Basically, chloramines are formed by chemically bonding chlorine with ammonia and adding it to our tap water. Yeah, that's right. Careful what you drink. Obviously, this is very significant to your Aquaponic system, especially during a nitrite spike. If you are unsure whether your water has been treated with chloramines, test for ammonia after off-gassing the chlorine, or call your local water treatment facility and ask questions.

There are several proposed solutions for chloramines such as Thiosulfate, Food Grade Ascorbic Acid (Vitamin C - 1000 mg/40 gal), Zeolite, campden tablets (available at many homebrew stores), and products such as AmQuel (sodium hydroxymethanesulfonate) that can be purchased at an aquarium store. Passing the water through a carbon filter before adding to the system has been recommended. Results vary depending upon how much Choramine is added to your municipal water supply.

Aquaponic systems have operated successfully with chloramines present, and problems usually present themselves during the hotter summer months.

Dissolved Oxygen (DO)

Of all environmental factors that affect an Aquaponic system, one of the most critical is the dissolved oxygen (DO) level in the water. If the DO level gets below 3 ppm there is a problem and it must be corrected quickly. Acceptable levels are between 4 and 5 ppm, but 6 and above are stellar. A drop in dissolved oxygen may come from the air pump being disconnected on a hot day, or too many fish in the tank.

Make certain that there are adequate air stones in your fish tank and they go all the way to the bottom of the tank. The longer the time the air bubbles are exposed to the water, the more increase in oxygen diffusion. Clean the air stones periodically.

Aquaponic Chemical Terms

Acidic – On a pH scale from 0-14, with 7 being neutral, acidic is anything under 7.

Alkaline – On a pH scale from 0-14 with 7 being neutral, alkaline is anything over 7.

Alkalinity - regulates the cushion (buffering) power of water to resist pH change. If the water has a higher alkalinity, it is more resistant to pH changes.

Ammonia – first component of the nitrogen cycle. Primary sources are excretions by the fish from their gills and conversion of decaying organic matter such as uneaten fish food, fish waste, and dead plant matter within the Aquaponic grow beds. Ammonia can build up and become toxic if not diluted or converted in the system.

Biological Filtration – A biological process that helps an Aquaponic system convert toxic wastes (ammonia and nitrites) to non-toxic nitrates.

Carbonate Hardness – Carbonate hardness (KH) is the measure of bicarbonate. (HCO_3^-) and carbonate (CO_3^{2-}) ions in the water; also called acid binding, acid buffering capacity, and alkalinity.

Calcium carbonate ($CaC0_3$) – Substance found naturally in chalk, limestone and marble, often used to buffer pH higher.

Chelated Iron – A form of iron that is more usable by plants in an Aquaponic system.

Chloramines – More stable than chlorine, chloramines are routinely added to municipal water supplies to kill bacteria. They are formed by mixing chlorinated water with ammonia. Chloramines cannot be off-gassed.

Chlorine – A gaseous element added to municipal water supplies to kill bacteria. Since chlorine is a gas, it can be removed prior to use in an Aquaponic system.

Cycling – Process of establishing a sufficient population of beneficial bacteria to complete the nitrogen cycle and neutralize toxins.

Cycled – The point at which sufficient population of beneficial bacteria are in an Aquaponic system to complete the nitrogen cycle.

De-Chlorinate – A process which removes chlorine. See Off-gassing

Dissolved Oxygen (DO) – A measure of oxygen dissolved in water.

General Hardness (GH) – A measure of the calcium (Ca^{++}) and magnesium (Mg^{++}) ions.

Hydroponics – The science of growing plants in a nutrient-rich solution without soil.

Nitrates – In an Aquaponic system, nitrates are the result of nitrites being converted by nitrifying bacteria. Nitrates are very beneficial to the plants.

Nitrite Spike – A period, usually during the cycling process, when a buildup of ammonia and nitrites occurs. These are toxic to fish, bacteria and plants.

Nitrites – In an Aquaponic system, nitrites are the result of ammonia being converted by nitrifying bacteria. Nitrites, like ammonia, are toxic to the system.

Nitrobacter – A bacteria which converts nitrites into nitrates as part of the nitrogen cycle.

Nitrogen Cycle – A process by which ammonia, via nitrifying bacteria, is converted into nitrites and then nitrates.

Nitrosomonas – A bacteria which converts ammonia into nitrites as part of the nitrogen cycle.

Off-gas – A term which refers to the removal of chlorine gas from municipal water.

pH – A scale used to express the acidity or alkalinity of a solution on a scale from 0 to 14, where 7 represents neutrality, less than 7 represents acidity, and more than 7 represents alkalinity.

PPM – Parts per million.

PPT – Parts per thousand.

PVC – Polyvinyl chloride – a plastic polymer often used for plumbing in Aquaponics, especially NFT-type systems.

Reagents – A form of liquid-based water tests which, when combined with the liquid to be tested, provides a color reading of water conditions.

Test Strips – A form of water tests that resides on a plastic strip which, after being submersed in the liquid to be tested, provides a color reading of water conditions.

Total Ammonia Nitrogen (TAN) – Ammonia reading which consists of both ionized and un-ionized ammonia.

Water Change – A measure taken to alleviate a water problems such as a nitrite spike or other system contamination.

Texas TransFarming Builder Series Supplement

Water Conservation with TransFarming and Aquaponics

Here in Texas we face myriad obstacles to growing food in a "sustainable" fashion. What does sustainable mean? Well, it has a lot to do with producing food in a manner that is not interrupted by "outside influences". One of the major outside influences here in Texas is the weather – long seasons of heat, extended periods of cold, rapid changes between those two conditions, and no rain in between.

The entire premise of TransFarming was started on the realization the weather here in Texas can be brutal and a different approach must be taken to combat the elements in light of our modern challenges.

At the core of all this is water. Without water, nothing prospers. TransFarming is about "re-thinking" traditional gardening methods to address *regional environmental challenges* like droughts and water restrictions, while keeping in mind techniques for prosperous food production. These approaches involve growing food in ways that conserve water.

Weather wise, not much has changed from the days of our ancestors, but they used vastly different approaches to dealing with the climate than we do today. Following are a few techniques used to conserve water on a TransFarm.

Wicking Beds
Wicking beds have proven to be a viable solution to the Texas heat and water conservation. These simple structures, based on a raised bed garden, incorporate a reservoir underneath the bed to store water. The garden is watered through an exposed pipe which then wicks water upward through the soil to the roots where water is needed the most. There is minimal evaporation.

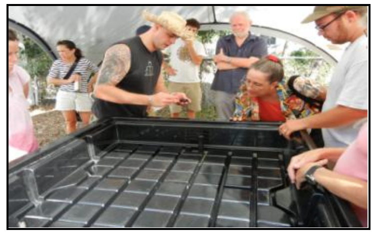


Traditional Raised Bed Gardens
Traditional raised bed gardening involves selecting the correct structure and materials for a specific outcome base on environmental factors such as shading, sun path, wind direction and desired crop. Additionally, soil composition will play a very large part in crop success and water conservation. A simple small hoop house may be desirable to protect from direct sun and winter cold.



Aquaponics
Aquaponics is the combination of aquaculture (fish farming) and hydroponics (soilless plant production). With Aquaponics, the nutrient-rich water that results from raising fish provides a source of natural fertilizer for the growing plants. As the plants consume the nutrients,

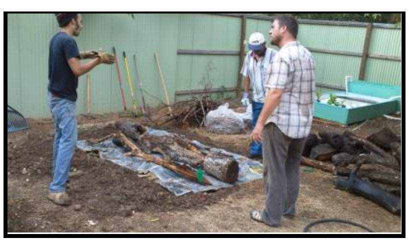
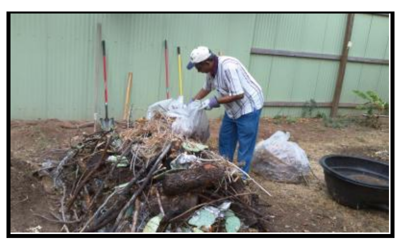
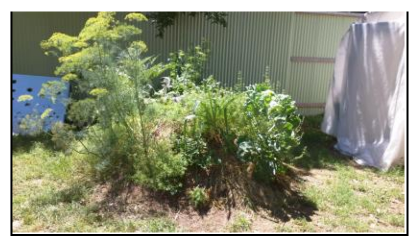
they help to purify the water in which the fish live. A natural microbial process keeps both the fish and plants healthy, and helps sustain an environment where all can thrive. Both the plants and fish are harvested.


HugelKulture

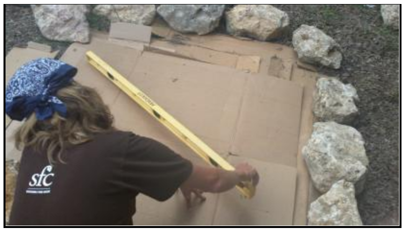
A HugelKulture is a type of raised bed garden that allows one to use organic materials that are too big to go in the compost. Over time, that is 3- 5 years, the materials in the bed decompose, and provide a slow release of nutrients for garden plants.

Because of its three-dimensionality, a HugelKulture raised bed garden combines the multiple functions of rainwater harvesting, catchment, and irrigation using no cistern, pumps, or pvc pipes. Done properly, there may be no need to water all summer!

Keyhole Gardens

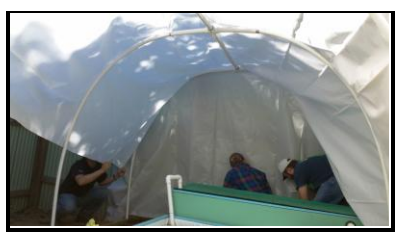
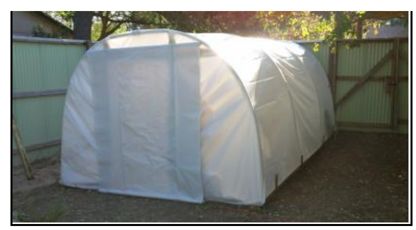
A keyhole garden uses the same principle as a HugelKulture in that decomposing matter is used to absorb and retain water in the soil. Large amounts of "rotting" wood and kitchen scraps are used in the soil which is stacked within layers of cardboard and paper. Kitchen scraps are also added to the bed via a foot-wide tube which nourishes the entire system. A wedge is cut in the circular bed to access the tube, which makes the garden look like a keyhole when viewed from above.



Hoop House/Monkey Huts

One of the major concerns with growing food (and fish) in the winter is the cold. The wind does not help much either. Greenhouses are expensive, and any constructed structures tend to be somewhat permanent.

Enter the simple Monkey Hut. These structures are by their very nature flexible, and designed to withstand strong wind and rain (dust too). Built correctly, they are easily dis-assembled in the Spring, or used to support a shade cloth in the Summer.

Vermiculture and Constructing a Worm Bin

Worm Composting is an excellent way to create organic matter for gardens and Aquaponic systems. They can be added directly to gardens and Aquaponic media systems, and also used to feed fish and chickens. Worms are important in the garden because they aerate the soil which helps lock in moisture. Worm farming includes choosing a worm and bin type, setting up the worm composting bin, maintaining the system, harvesting compost and worms, making and using worm tea, and such activities.