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The Aquaponic Cycle

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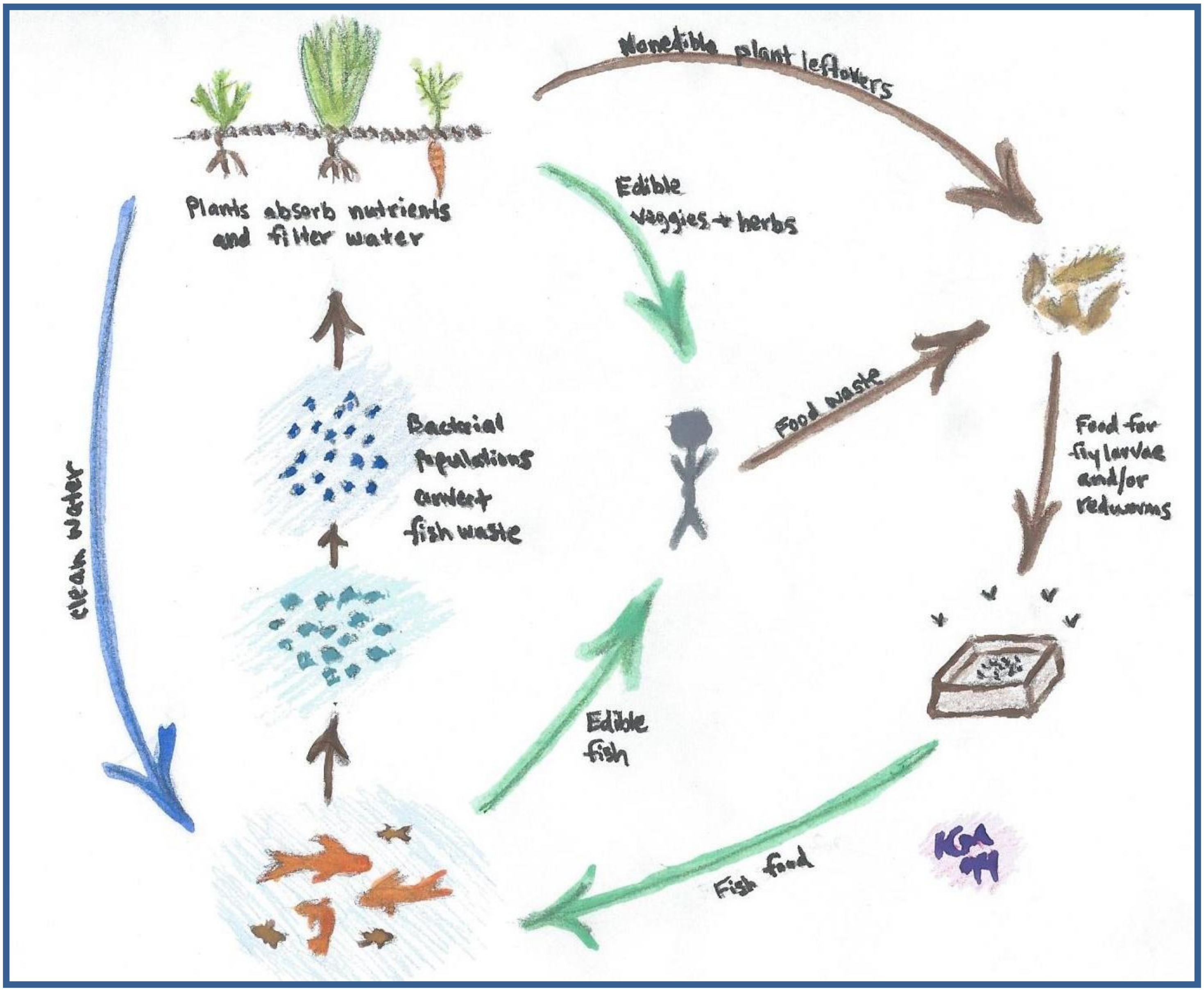

Aquaponics is a symbiotic combination of hydroponics (method of growing plants in water, using mineral nutrient solutions, without soil) and aquaculture (farming of aquatic organisms), or the process of growing plants and fish together in one integrated system that relies on the biotic relationship between fish and bacteria. Fish waste is converted to forms useable by plants by a healthy population of bacteria. For instance, ammonia (a form of nitrogen toxic to fish) is first converted to nitrites by bacteria and then to nitrates by another type of bacteria. Since water is a nutrient delivery system, these nitrates are then taken up and used by the plants, returning clean water to the fish. Essentially the plants filter the water for the fish and gain biomass at the same time, all in one sustainable ecosystem. In addition to nitrogen, phosphorous and potassium make up the three primary plant nutrients. Since these systems rely on natural processes, there is no need for chemically derived fertilizers or nutrients. This results in an efficient system with no environmentally hazardous waste being produced.

The commercial industry of aquaponics is rapidly growing; however, these systems can easily be established in backyards or bright rooms, by anyone. Home-based aquaponic systems can vary greatly in size. Outdoor systems may utilize a small area of a backyard, existing space around a pond, or even an entire backyard. Indoor systems may be set-up with plastic tubs near bright windows to minimize the usage of plant lights, or even added on to an indoor aquarium. Both outdoor and indoor aquaponic systems can provide fresh, local food for a single person, a family, or even multiple households. The amount of food and fish produced only depend on the size of the working system.

There are many benefits to choosing aquaponic systems over traditional growing

methods. The relationships between the fish, bacteria, and plants keep the water quality high while allowing the plants to gain biomass. Water use is greatly reduced compared to traditional gardening by circulating it through the system, rather than allowing it to percolate down to the ground water or run-off in the surface water. Thus, there are no concerns regarding soil erosion and run-off with aquaponics. Evaporation from the substrate (soil in normal gardening) is also minimized by the circulating water and nutrient delivery system. Only water loss through leaf transpiration and harvesting is comparable to what is seen in soil-based plant production. Since the fish waste provides nutrients to the plants, the use of chemical fertilizers and nutrients is also greatly reduced. Pesticide and herbicide use is eliminated to sustain the fish. If an additional greenhouse is used to cover the system, fresh produce and fish can be grown nearly year-round in most climates. The water in a well functioning aquaponic system never needs to be replaced, unlike in hydroponic systems where nutrient imbalances occur over time. The chemicals that build up in hydroponics systems can also pollute waterways if not disposed of properly. Aquaponics systems also avoid the toxicity problem of built up nitrites seen in aquaculture systems. The nitrites are converted into nitrates by bacterial populations in established aquaponic systems, which the plants take up and utilized as their nutrient source. Aquaponics systems rely on natural processes between fish, bacteria, and plants, to provide many benefits compared to other methods of growing food.

Physical Setup

The simplest aquaponic system is a media filled bed. Plants are grown in containers filled with gravel or an expanded clay medium that allows the plants to establish supportive

root systems. Nitrogen-rich fish tank water is pumped over the beds in one of two ways. A continuous flow of water can be circulated through the growing medium and fish tank. However, it is more common to circulate the water by periodically flooding and draining the beds. This lowers electrical consumption by not having to constantly pump water through the system. A timer can easily automate the pump to flood and drain at specific intervals. In addition to the pump, an air bubbler will require some electrical consumption to keep the water sufficiently oxygenated.

Another method to implement aquaponics is through Deep Water Culture. These systems employ floating rafts, which allow plant roots to be constantly immersed in nutrient rich water. This method can involve simply floating a few plants on top of an existing aquarium, or by utilizing deep plastic tubs. This method is commonly used in the commercial industry by circulating water through a large fish rearing tank and large raft beds of floating plants.

A less common approach to aquaponics is through a Nutrient Film Technique commonly used in hydroponics. In these systems, a very thin flow of nutrient rich fish water is pumped through a mechanical filter and enclosed piping, such as PVC. Plants are situated in circular openings along the top of the pipe so that the roots can access the thin film of flowing water and absorb essential nutrients. This method is generally best for leafy vegetables with small root systems that the chosen piping can support. In addition, the shallow water depth means any solid waste will get stuck in the plant root systems. Thus, the need to mechanically filter solids from the water makes this the highest maintenance and least commonly used method.

Establishing the Bacterial Community

Aquaponics systems may be established in a multitude of simple or complex manners, as long as the components of supporting the natural processes between fish, bacteria, and plants are understood. Arguably the most important component of starting these systems is a well-established community of bacteria. However, not just any bacteria will suffice. The bacterial community must contain species (*Nitrosomonas*) which convert ammonia (NH_3) waste into nitrites (NO_2^-), and other species (*Nitrobacter*) that convert nitrites into useable nitrates (NO_3^-) for the plants.

$$NH_3 + 1.5\,O_2 \rightarrow NO_2^- + H^+ + H_2O$$

$$NO_2^- + 1/2\,O_2 \rightarrow NO_3^-$$

$$\Sigma = NH_3 + 2\,O_2 \rightarrow NO_3^- + H^+ + H_2O$$

There are many different ways to establish these important populations of bacteria; however, both populations must be present for plants to obtain their required nutrients and survive. The most efficient way to start a system is to inoculate it with bacteria from an existing system, an aquarium, or a pond. This can also be referred to as "seeding" the system. It is important that the new system is seeded with bacterial populations from established, disease-free communities. Aquarium filters contain high concentrations of the desired beneficial bacteria, as do samples of gravel. Local pet shops are likely to provide a sample of gravel, water, or a used filter from an establish aquarium. However, it must be from a disease-free tank to avoid transferring undesired diseases to the new seeding system.

The desired bacterial populations can also establish naturally in the system - it just takes longer. A source of ammonia must be present in the water to draw the desired bacterial species, such as food grade ammonia. A dead fish, or fish feed will also break down and release ammonia into the system.

In order to make sure the correct bacterial populations are established, it is recommended to purchase a water testing kit to test the levels of pH, ammonia, nitrite, and nitrate periodically until the system is established in converting ammonia to useable nitrates. The amount of time required to establish efficient conversion of ammonia to nitrite and then to nitrate (known as cycling) depends on how quickly the desired bacterial populations establish themselves. Establishment through seeding the system from an existing system or aquarium can take days, while drawing bacteria with just ammonia may take weeks. Once established, the water should be tested periodically. Then imbalances can be fixed before problems resulting in fish death arise.

Adding Fish

Once the beneficial bacterial populations and efficient cycling are established, fish may be slowly added to the system. It is recommended to start with cheap feeder fish, or goldfish, in case some die initially. A lightly stocked system is more resilient if system imbalances arise. The amount of fish that can be sustained in the system depends on many factors, including oxygen levels, water flow, feed rates, and how many plants will be grown. It is important to make sure the water contains enough dissolved oxygen to sustain the fish. If there are too many fish in the system, then there is less oxygen available for each of them. Higher water temperatures, as

well as high concentrations of dissolved salts, decrease dissolved oxygen. Gravitational oxygenation will dissolve more oxygen into the water, by allowing the water to fall back down into the fish tank after it has circulated through the grow bed. Although, this will need to be supplemented with an air diffuser or bubbler to provide enough dissolved oxygen for sustaining the fish.

Aside from dissolved oxygen levels, there are other important factors to consider for the quality of water in the system. A dip or spike in water temperature can cause stress on the fish, which may lead to death or susceptibility to disease. A mechanism of heating or cooling the water may be needed depending on the climate and optimal temperature range for the chosen species of fish. Different species thrive better in different climate locations. It is also important to avoid using water with high concentrations of dissolved salts or chlorine. If chlorinated water is the only water available, then the chlorine must be removed before introducing any bacteria or fish. This can simply be accomplished by exposing the water to air and sunlight for a few days. Additives can also be added to neutralize the water, or it can be run through a filter if available.

Varying from climate to climate, there are many different fish species that can be used in aquaponic systems. It may be best to begin systems with inexpensive goldfish in case some die while the system balances. They are very hardy fish and easily obtainable. Koi fish are very popular ornamental fish to use in these systems, but they can be expensive and should only be added to well established systems. Tilapia is a very popular species for aquaponic systems. They are fast growing, easy to breed, and can withstand poor water conditions. Their only downfall is that they require warm water, and are unable to grow below 61^{o}F. Fish species should be

chosen based on local climate conditions. This eliminates any hassle of heating and cooling the system water. Trout are more adapted to cooler climates and thrive between 50-65^{o}F. This would be more of an ideal species for the climate of Michigan, as long as the fish were moved indoors during the colder winter months. Some types of carp and catfish can also be used; however, some have poor reputations of being desirable to eat. Whether or not a fish is chosen based upon consumption, care should be taken to determine if the species is locally invasive and to be avoided.

Closing the Loop

A sufficient amount of suspended micro and macro nutrients is essential in the water of an aquaponics system. The majority of these nutrients arise from the fish waste produced by the original fish food. Many plants are able to grow with little available nutrients; however, their look and taste will not be satisfactory. If the chosen plants are fruiting plants, then they will struggle to produce normal sized fruits. A lack of nutrients also makes the plants more vulnerable to pests and disease.

Since both plant matter and fish are periodically harvested, aquaponic systems are not considered closed loop systems. A closed loop system would not require any additional inputs once established. Since matter is being removed from the system, something must replace it for the cycle to continue. Fish feed must be added to these systems so additional plants can grow and be harvested, or removed from the system. Fish feed pellets are available on the market; however, similar to other processed foods, these feeds can be expensive and come from unsustainable methods of production. The fish feed is the basis of where the plants will

derive their biomass. Higher quality fish feed thus leads to higher quality crops for consumption. If an aquaponics system is being pursued to avoid unsustainable methods of industrial crop production, then one must be careful in what fish feed is chosen as input for the system. There are multiple fish feed generating pathways available to supplement the aquaponics cycle and essentially "close the loop" to establish a fully sustainable ecosystem. The most widely used species for this purpose are duckweed, black soldier fly larvae, and redworms.

Duckweed is an aquatic plant which floats at the surface of slow, still bodies of water. This plant has very high protein content and pairs well in feeding tilapia. It has potential to double in size every few days, allowing a consistent harvest. Additionally, excess duckweed can be dried for feed during winter months. This rapid growth rate, however, makes duckweed a potentially invasive species if introduced to new ecosystems. Care should be taken in containing the duckweed to a small outdoor pond, or indoor aquarium. It should not be grown directly in the aquaponics system since the duckweed is intended to act as an input of nutrients for the fish to consume. If it grew directly in the system, then it would be removing nutrients from the system.

Black soldier fly larvae can easily be produced through modified methods of composting. The adult flies are unable to bite or sting. They are also territorial and ward off other types of flies that may bite. Their lifecycle can be sustained with daily food scraps and the larvae are high in both protein and fat. Females lay eggs directly in the decaying food scraps that the larvae hatch in and consume. These larvae naturally leave their feeding site in search of soil to burrow into for the stage of metamorphosis. Clever bins have been designed on the

market to capture the leaving larvae which can then be utilized as a fish feed input to the aquaponics system. Redworms can also be grown in traditional compost bins containing daily food scraps. They live close to the surface and reproduce quickly, making them an ideal fish feed.

Duckweed, black fly larvae, and redworms are all high in protein, fat, and the necessary nutrients that fish need to thrive. A combination of composting and growing duckweed would utilize old food scraps and the high protein content of duckweed. However, any fish feed can be detrimental to an aquaponics system if used too heavily. Fish should be fed as much as they can consume within 3 or 4 minutes. Remaining food should be removed from the tank. If uneaten food is allowed to sink and decompose, it will consume dissolved oxygen and increase ammonia levels. This puts stress on the balance of the system and can cause harm to the fish.

Adding Plants

Nearly any type of plant can be accommodated and grown in an aquaponics system, so it is best to plant crops that the grower enjoys. Keep in mind that plants with larger root systems require deeper growing beds and more time to mature, while leafy green vegetables can produce within a few months. Fruiting plants, such as tomatoes, cucumbers, and peppers require more nutrients to reach maturity in the system. This requires a well-established community of bacteria to convert ammonia into enough useable nutrients. If media filled beds are being used, plants are able to thrive even when close together. The lack of competition for water (as occurs in regular soil) allows for dense planting. In addition to planting densely, it is efficient to use all of the space available around an established system. A fence may be placed

along the back side of the grow beds for plants that grow up or climb. Large plants like pumpkins can even spill over the edge of the beds as long as their roots are in contact with the water system.

It is best to have a mixture of mature plants, half grown plants, and seedlings in the beds at all times. This allows for continual, steady harvesting. If everything was harvested at once, then there would be nothing to take up all of the nitrate nutrients produced by the bacteria. A buildup of nitrates will in turn harm the fish population. This makes it necessary to plant additional seeds when mature plants are harvested, staggering plant growth in the system. If the growing medium is fairly large, then it may be easier to germinate seeds in tiny cups of soil until they are stable enough to be transferred into the media bed. Make sure to remove all potting soil before transferring to avoid any system contamination.

Location

Before an aquaponics system is set-up, it is important to choose an appropriate location for the system. There needs to be power access for both water and air pumps. At least 4-6 hours of adequate sunlight are required each day for good plant growth. If the system is being set-up indoors, a plant light may be needed to supplement light coming in from the windows. The system should get plenty of sunlight if it is set-up outdoors. However, keep in mind that the fish do not require sunlight. It is actually best to avoid having sunlight on the fish holding tanks, as it helps avoid algae growth. An opaque tub may be used to hold the fish, or a wooden base may be constructed around the tank to shield out the sunlight. Floating plants in the fish holding tank also allow for more coverage from the sun. This also offers some shelter for the

fish to feel protected and less stressed. It may be useful to grow an invasive plant, like mint, that could otherwise overtake an entire growing bed. If the system is being set-up indoors, it is also important to make sure the structure will be able to physically support the finished system once it is filled with water.

A greenhouse is not necessary, but it is generally useful for any outdoor aquaponics set-up. They greatly extend the length of the growing season into cooler fall and spring months. Year-round production is even possible with greenhouses in more moderate climates. If winters get too cold, then the system may need to be broken down and moved indoors until the spring thaw. Greenhouses also help protect from rain, wind, and keep out more pests than if the system was wide-open to the outdoors.

Healthy plants typically repel pests and diseases naturally, as do healthy fish. The best preventative care is to keep a strong system running with enough nutrients for all of the plants to flourish naturally. If pest problems arise, no pesticides may be used on the system. This would harm and very likely kill the fish in the system. It is best to remove the affected plants and determine the source of the pest or disease before planting replacements. Fungal infections often occur from a lack of air circulation around the bases of too densely planted areas. If fungal problems arise, it may be useful to use a fan for extra air circulation around the bases of plants. There are many natural ways to deter pests too. For example, applications of the natural soil borne bacteria *Bacillus thuringiensis* can easily control caterpillar problems. A small saucer of beer can be utilized to draw and drown undesired slugs. Potassium bicarbonate is non-toxic and can be sprayed on plants with mold or fungus to balance the pH. Colored sticky traps are also used for aphids and whiteflies that may wander into the system.

Like the plants, keeping the water-based system balanced and healthy will avoid any major pest issues from the beginning. It is important to remember that this includes good aeration and water movement in the fish holding tank. Bacterial and fungal infections can easily arise if the fish tank is overpopulated and solid wastes are allowed to accumulate. This places the fish under extra stress, which makes them more susceptible to infections. A few plastic plants in the fish holding tank can provide extra shelter for the fish to hide in and feel protected. This can help relieve some stress from being in close quarters with other fish, while leaving all of the nutrients available for the plant matter in the media bed. Certain fish fungal infections may require fungicide to be added to the fish tank. However, the water should not be pumped through the growing bed until the treatment is finished. In the meantime, a regular aquarium filter can remove the fish waste preventing nitrates from accumulating in the absence of plant uptake.

Nutrient Balancing

If a system gets out of balance, deficiencies may occur in the plants. This is generally avoided if high quality fish feed is being put into the system. The simplest way to deal with deficiencies is to supplement the system with the addition of seaweed extract, which contains very high levels of many minerals and micronutrients. Seaweed extract is readily available under many brand names and inexpensive. This may be done once or twice a year for precautionary measures, as sometimes deficiencies are difficult to see. However, most established systems do not need to be supplemented.

Aquaponic systems depend on natural processes that occur between fish waste and

bacteria to produce edible plant material for both commercial and home growers alike. These systems provide many benefits compared to traditional methods of growing food. There is a large increase in the conservation of water with these systems. Furthermore, there is no need for chemical fertilizers, pesticides, or herbicides. The only input needed for the aquaponics system to flourish is fish feed. Fish feed can be generated through other renewable processes alongside aquaponics to essentially "close the loop" and yield a sustainable system. Aquaponics systems are a great opportunity to start growing healthy, fresh food right at home. The simplest approach is to start small by floating a few herbs on an existing aquarium.

Try it out yourself!

Sample schematic of a media filled flood and drain aquaponic system. A timed pump periodically floods the media filled bed, delivering suspended nutrients to the root systems for filtration. Once the bed is filled, a bell siphon returns the filtered water to the fish holding tank, providing some gravitational oxygenation. The amount of dissolved oxygen is increased to sufficient levels using an air bubbler in the fish holding tank. A wooden frame and rope strung along the backside allows climbing plants to be easily added in the system. In addition, a greenhouse or plastic cover is useful in protecting outdoor systems.