A Practical Introduction to Aquaponics

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Abstract

This paper provides a comprehensive look at aquaponics, which is an integrated recirculating system that can grow produce and fish. This paper begins with an explanation of what an aquaponics system is, followed by a brief overview of the history and development of modern aquaponics. Following this, I discuss how an aquaponics system functions, both on a macro and micro scale, paying attention to the importance of the nitrogen cycle within the recirculating system. There are three different system designs that are most common, which I briefly discuss, before going into the basic system requirements including hardware, software, and fish and plant species. The remainder of this paper details how to set up an aquaponics, as well as how to maintain it.

Introduction

Aquaponics is a recirculating, bio-integrated system with two main system elements – an aquaculture sub-system and a hydroponic sub-system. Aquaculture is the farming of fish and other aquatic organisms in various types of water environments. Hydroponics is the practice of growing plants using mineral nutrient solutions in water, instead of growing plants in soil. These two systems connect via a water medium that continuously cycles between them, resulting in a closed, self-sustaining system that is a highly effective and efficient method of producing both plant and fish crops.

Aquaponic systems are recirculating systems, meaning they are constantly circulating outputs back into the system. The base of an aquaponic system is the aquaculture system, where large quantities of fish are raised in a recirculating system (Rakocy et al., 2006). Many of these modern systems treat water to remove any toxic waste products and then reuse it. In the process of reusing water, non-toxic nutrients, and organic matter often begin to accumulate in large amounts (Rakocy et al., 2006). These nutrients and organic matter are not utilized by the fish and often go to waste via cleaning and large water changes, which requires a large input of water (Rakocy et al., 2006). However, if these aquaculture by-products are channeled into a second crop that directly benefits from them, while also benefitting the main fish production system, these nutrients are not wasted. This is where the hydroponic aspect of aquaponic systems becomes vital. The main aquaculture system for fish production can be reconfigured so that the flow of water is channeled to another unit, located with the hydroponic plant producing component (Rakocy et al., 2006). This is incredibly beneficial to overall crop health and yield because aquaculture wastewater is abundant in nitrogen and many other secondary elements that are essential to plant growth. Hydroponic systems often require a large input of artificial fertilizers given that pure water is low in essential nutrients - by channeling aquaculture wastewater into a hydroponic system, the crop plants are given a natural source of these essential elements.

Due to its sustainable nature, aquaponics has the potential to revolutionize the food production industry. Many systems used in food production today, like plant production and fish farming, carry vast amounts of negative environmental impacts, including soil erosion, pollution, and the production of greenhouse gases (Konig et al., 2016). Aquaponics is a highly sustainable, complex food production technology that is valuable in an increasingly urbanized world where lack of natural spaces and food-insecurity are becoming larger issues every day (Konig et al., 2016). Aquaponics can be a viable solution to these issues, possessing features that are suited to both urban and rural areas. Aquaponic systems allow for the highly intensive production of fresh, high-quality food with low water usage and little impact on the climate or biodiversity (Konig et al., 2016).

Background and Historical Information

Aquaponics and integrated aquaculture systems have a long, fascinating history with well documented "blue revolutions," where indigenous societies have used these techniques to provide for their growing populations (Arco and Abrams, 2006). There are many recorded instances of ancient societies utilizing integrated aquaculture systems in similar ways. The earliest accounts of societies utilizing systems like aquaponics are found in ancient continental Asia and pre-Hispanic Mesoamerica (Arco and Abrams, 2006). It is difficult to pinpoint a specific timeline of aquaponic development in continental Asia, as it has been theorized that many areas across Asia developed integrated aquatic-agricultural practices independent from one another (Costa – Pierce, 2015). However, it is widely accepted that integrated aquaculture systems were first developed in ancient South China. There have been many archeological discoveries indicating the existence of irrigated agriculture systems, namely, clay models that's show a rice-field with "over 18 varieties of aquatic plants and animals" (Costa – Pierce, 2015). These discoveries place the beginning of aquaculture during the Han Dynasty, which dates from 200BCE to 220CE (Costa – Pierce, 2015). This practice of rice-fish farming meant the production of rice and fish together in large fields, which could have taken many forms. It is likely that fish were grown one after another in the same field, or simultaneously in fully integrated compartments where fish lived within the planted rice crops (Costa – Pierce, 2015). Overall, the integration of aquaculture with aquatic plants has been apparent in records found as early as 250 to 150 BCE.

Pre-Hispanic Mesoamerica is another example of the historical utilization of integrated aquaculture systems. A system known as “Chinampas” has existed throughout Mesoamerican history and has been integral to the development of many ancient societies, including both the pre-Aztec Xaltocameca civilization and the Aztec civilization (Morehart, 2012)(Arco and Abrams, 2006). The Chinampas system consisted of crops being grown on top of raft-like islands that floated in the shallow areas of lakes. These shallows were likely a diverse habitat to many small aquatic organisms that contributed to the health of this system. This later developed to be in specially constructed canals, which allowed plants to be systematically watered using various methods like pot irrigation and the splashing of water onto plants with canoe paddles (Morehart, 2012) (Arco and Abrams, 2006). In both iterations of the chinampas system, nutrient-rich water, waste, and mud were used to irrigate and fertilize the crops on the islands (Morehart, 2012) (Arco and Abrams, 2006). Although the foundation is the same, contemporary aquaponic practice differs greatly from these early systems.

The conceptualization of modern aquaponics is credited to William McLarney, John Todd, and Nancy Jack Todd of The New Alchemy Institute. Although it closed in 1991, this institute pioneered research on integrated aquaculture systems through the 1970s and 80s. Their landmark creation was “The Ark,” which they described as a “polycultural food-producing system” (Wade, 1975). The Ark system consisted of three greenhouse covered ponds built along an incline so that the ponds were configured one below another (Wade, 1975). The three ponds were a structured system that depended on one another to grow edible fish. The first pond housed a lively bacterial colony that cleaned water that had been recirculated from the bottom-most pond that housed edible fish (Wade, 1975). This flowed into the second pond, where algae and small aquatic organisms grew and were used as fish food for the fish growing in the third pond (Wade, 1975). This pond system provided water to the greenhouse built above the ponds, where vegetable crops were grown (Wade, 1975). The design of this system became the basis for many contemporary aquaponic systems, as well as the basis for aquaponics research and publications.

In the 1980s, Dr. James Rakocy began extensive research in developing aquaponic technology at the University of the Virgin Islands (UVI), with an emphasis on water and nutrient recycling systems (Diver, 2005). Rakocy's research also developed "biofloc systems," where settling and filtration systems were used to extract solid waste from water systems to be later used as organic fertilizer (Diver, 2005). Rakocy and his colleagues were also the first to develop a type of hydroponic system called Deep Water Culture, and among the first to develop a fully functioning commercial aquaponic system that could grow produce and fish on a larger scale (Diver, 2005). By the 1990s, the aquaponic system at UVI was so successful that Racoky and his team began a training program that taught over 500 students from across the U.S states, territories, and 56 other countries how to implement an aquaponics system at various scales and production need levels (Diver, 2005).

At the same time, Mark McMurtry and Doug Sanders developed what is referred to as the North Carolina State System (Diver, 2005). Diver describes this system as an "aqua-vegeculture system based on tilapia fish tanks sunk below the greenhouse floors"(2005). This system was largely self-reliant, as the only regular input required was fish feed. This system highlighted the benefits of integrating aquaculture and vegetable production, which conserved water, increased production of fish protein, and reduced operating costs (Diver, 2005). In the early 1990s, Tom and Paul Speraneo developed the Speraneo System, by modifying the way tilapia was raised in the North Carolina State System and attaching it to a greenhouse (Diver, 2005). They later expanded this system to a full-size commercial greenhouse. It soon became the model standard for commercial and educational operations.

How Does the System Work?

Macro Scale

The essential elements of any aquaponic system are a fish tank, solids removal component, a biofilter, a hydroponic component, and a sump (Rakocy et al., 2006). The basis of the aquaponic system is the fish tank, where the chosen stock of fish is raised. The fish produce waste, which enriches the water with many mineral compounds. This liquid waste is first treated to reduce the amount of any solid organic matter that is in the water using the chosen solids removal component (Rakocy et al., 2006). This water is then treated a second time by circulating through a biofilter, which works to remove any excess ammonia and nitrites (Rakocy et al., 2006). Once the water has been treated for both solid waste and harmful excess chemicals, the water then flows into the hydroponic unit. Once the flow of water enters the hydroponic unit, the plants can absorb the remaining beneficial dissolved nutrients that are essential to healthy plant growth (Rakocy et al., 2006). Bacteria that are present in the hydroponic unit also work to remove any residual ammonia and nitrates (Rakocy et al., 2006). Finally, this purified and oxygenated water is collected in the sump, or water reservoir, and is then pumped back into the fish-rearing tank, where the cycle begins again (Rakocy et al., 2006).

The process described above is a very basic form that can be modified and configured in many ways, from the system structure to specific inputs. In many cases, the biofilter and hydroponic components can be merged by including plant support media in the hydroponic unit. This plant support media, like pea gravel or sand, can function as a biofilter media and capture solid waste particles (Rakocy et al., 2006). Plant support media also provides a surface for the ever-important nitrification process that the system depends on (Rakocy et al., 2006).

Micro Scale: Bacteria and the Nitrogen Cycle

The foundation of any successful aquaponics system is the bacteria colonies that thrive within them and the nitrogen cycle that takes place within any aquatic ecosystem. The nitrogen cycle is a process that provides biological filtration that is essentially a natural waste management system (Flavius and Grozea, 2011). Many aquaponics systems are almost entirely closed-loop systems, where the only inputs required outside of initial set up are fish food and appropriate exposure to sunlight (Flavius and Grozea, 2011). When the fish within the system eat, they produce waste that is made up of ammonia that is almost entirely water-soluble (Flavius and Grozea, 2011). As the fish waste dissolves in the water, it begins to cycle through the aquaponic system. This can be highly problematic, as high levels of ammonia are toxic to fish – excess ammonia can burn the kills of fish and choke off their oxygen supply (Flavius and Grozea, 2011). Ammonia is also completely useless to plant growth. Mechanical filtration systems, whether that be a standard aquarium filter or a solid-waste removal component, work to remove any sort of solid or decaying sediment waste that is present in the water (Flavius and Grozea, 2011). However, this does not work on microscopic particles and compounds that have already dissolved into water (Flavius and Grozea, 2011).

This is where the ever-important bacteria colonies become vital, which, as stated above, acts as a natural biofilter for the aquaponics system. There are multiple classes of bacteria present that work to convert ammonia. *Nitrosomonas* bacteria use oxygen present in the water to consume and convert ammonia into a by-product called nitrite (Nitrogen Transformations in Aquaponic Systems, 2015). Nitrite is generally toxic to fish but is much more tolerable than ammonia as fish can withstand twice the amount of nitrite when compared to their tolerance for ammonia (Nitrogen Transformations in Aquaponic Systems, 2015). Following this, *Nitrobacter* bacteria consume this nitrite and convert it into nitrate, which is a non-toxic chemical compound that plants must have in order to thrive (Nitrogen Transformations in Aquaponic Systems, 2015).

Given that the nitrogen cycle is integral to the success of an aquaponics system, it is important to discuss ways to maintain the health and productivity of it. The nitrifying bacteria occur naturally in any aquatic system, but generally, they need lots of space to fully thrive(Flavius and Grozea, 2011)(Nitrogen Transformations in Aquaponic Systems, 2015). Bacteria colonies grow on surfaces within an aquaponic system, so maximizing available surface area in the system will directly translate to a larger bacteria colony, thus creating a stronger biofilter to convert ammonia and purify water (Flavius and Grozea, 2011)(Nitrogen Transformations in Aquaponic Systems, 2015).

Different Aquaponic Systems

Aquaponic systems can vary greatly in their structure and design. When choosing a system design, it is important to think critically about the intended use and scale of the system, as this has large implications on the overall size and capacity of the system. The type of crop one wishes to grow is also an important factor, as the system capabilities must be matched to the crops depending on the specific growing conditions needed. This includes temperature ranges, nutrient demands, growth rate, weight, and root density. The environment that the aquaponic system is in another important factor, as annual, seasonal, and daily temperature changes will have a direct effect on the system productivity. Each system type has certain characteristics that will require a different level of expertise, both in aquaculture and horticulture.

The biggest difference between aquaponic system types is variation in the hydroponic system within it, while the aquaculture component remains relatively the same. The three most common system designs are Media Beds, the Nutrient Film Technique, and Deep-Water Culture (DWC).

Media Beds

Media Beds, also called Flood and Drain or “Ebb and Flow,” aquaponic systems are user-friendly and generally well suited for hobbyists and home gardeners. Media Beds are also the easiest systems to build and maintain as they are rather simple. In a media-based system, plants are grown in a planting media like gravel, expanded clay beads, and lava rock (Timmons, 2010). The media functions as a filter for organisms, parasites, and older solid waste materials. The media also provides excellent surface area for the necessary biofilter to grow, which helps reduce ammonia-waste (Timmons, 2010). The plant media is often held in large containers or grow beds, and the water from a separate fish tank is pumped or drained into the grow beds (Timmons, 2010). The plants have immediate access to water, and the media often holds onto water longer, which ensures that plants have plenty of time to absorb necessary nutrients (Timmons, 2010). Thanks to the double filtration, the water is purified and then drained back into the fish tank.

The system is run primarily by flooding and draining the grow beds with water by using a bell siphon to automatically drain the water once it reaches a certain saturation point in the media bed (Timmons, 2010). This draining process has an added benefit of drawing oxygen down into the grow bed, which supports the health of bacteria colonies and the plants (Timmons, 2010). This continuous regular cycle provides all the necessary nutrients for the plants to grow without the use of soil and artificial fertilizers.

Nutrient Film Technique (NFT)

The Nutrient Film Technique is a hydroponic growing technique that has been adapted to work within an aquaponics system due to the simplicity of its design and flexibility within many environments. In NFT, plants are grown in long narrow channels that run horizontally with small holes that are spaced evenly apart (Timmons, 2010). The plants are suspended in grow baskets, and the grow baskets placed in these holes, which allow the roots to dangle down into the channel (Timmons, 2010). A pump sends a continuous thin stream of water into the bottom of each channel, where it flows over the plant roots (Timmons, 2010). This provides the plant roots with adequate levels of water, nutrients, and oxygen. Once the water reaches the end of the channel, it flows back into the fish tank via a downward channel caused by a slight incline (Timmons, 2010).

The NFT system requires a separate filtration system to clean the water of any solids or fish waster before it enters the channels (Timmons, 2010). Otherwise, the waste can build up, and the roots can be blocked from getting oxygen. The NFT system also requires an additional biofiltration component because the system does not have enough surface area to support a bacteria colony that is essential to system health (Timmons, 2010). This is usually accomplished by introducing another container into the system that is situated after the solid filter, but before the NFT channels (Timmons, 2010). This container can take any form, just as long as it holds a porous medium that is heavily aerated, like the expanded clay pebbles mentioned before.

Deep Water Culture (DWC)

The Deep-Water Culture system, also known as the Raft System or Floating System, of aquaponics is one of the simplest and most efficient methods of growing produce (Timmons, 2010). In DWC, plants are grown on raft boards (commonly foam boards) that float on the surface of a container where fish are housed (Timmons, 2010). Plants are supported in the raft boards by net pots filled with growing media, and the plant roots hang down into the nutrient water (Timmons, 2010). This allows the plants to absorb large amounts of nutrients and oxygen, aiding in rapid growth. An air pump is necessary to oxygenate the water for the fish and help the roots breathe.

System Requirements

Aquaponics systems can vary greatly in system type and design, and much of that will be determined by personal preference and needs. However, there are basic components that are essential to the functioning of any system design. The components necessary for an aquaponics system can be divided into two categories – the hardware and the software. The hardware components are the materials and equipment needed to build the system. The software components are the supplies that are needed to maintain the system once the initial setup has taken place.

Hardware

The most important hardware requirements that are the foundation for any system are the fish tank and the grow bed that you choose, as both determine the size and yield of your system. The fish tank and the grow bed determine such things due to the volume relationship between them (Bernstein, 2014). The total volume of the grow bed that you connect to a fish tank should be equal to the volume of the fish tank (Bernstein, 2014). In other words, in order to allow for appropriate filtration, there needs to be a 1:1 volume ratio. The fish tank and grow bed also have similar material requirements (Bernstein, 2014). That is, both must hold a high volume of water without leaking, bowing, or cracking, and must be non-toxic to all living components of the system (the fish and the plants).

In order to determine the appropriate sizing of both, you must first determine the ideal total grow bed area in square footage (Bernstein, 2014). From this grow bed area, you can determine the stocking density required using a 1:1 ratio, where 1 square foot of grow bed surface can support 1 pound of fish (Bernstein, 2014). This stocking density will allow you to determine then the fish tank volume, where 5-10 gallons of water is needed for every 1 pound of fish(Bernstein, 2014).

Outside of the fish tank and the grow bed, there are a handful of universal hardware pieces that almost every system type and design will require. Some of the essentials include an energy-efficient pump to pump water, tubing to transport water to and from the grow beds, a siphon, an aerator (commonly an air stone), a temperature control device if the system is outdoors. The configuration of these hardware pieces will depend on the system type chosen, as well as the individual system design.

Software

The software needed to manage and ensure that your system is running efficiently is mainly related to caring for the fish that are housed within your system. It is important to utilize a cycling kit as a source of ammonia and nitrifying bacteria to initiate the nitrification cycle to get the aquatic environment ready for fish. This will also prepare the system for the safe introduction of fish. Once the nitrification cycle is established, a water quality test kit is needed to maintain appropriate levels of chemical compounds in the fish tank. This will allow for regular testing of critical water quality parameters that are necessary for optimal fish and plant health. Another critical part of managing an aquaponics system is adjusting pH as necessary, as both the fish tank and the crops have specific pH needs (Bernstein, 2014). Additional testing and monitoring equipment are required, as there are several water quality parameters that are important outside of pH and what a water quality test kit can identify (Bernstein, 2014). This includes temperature, iron levels, and dissolved oxygen levels.

Regarding fish care, there are obvious requirements such as fish food and fish care products, like fish nets and fish health therapy solutions. Fish food should be chosen to meet the nutritional needs of the fish at various stages of growth, as well as appropriate pellet sizing to ensure there is no hazard for the fish (Bernstein, 2014). There are additional requirements that are specific to plant care, with the most obvious being seeds and seed starting supplies, such as germination trays or a seed starting kit to help get your plants off to a good start. Items such as pruning shears, gloves, and other gardening supplies are also necessary for plant upkeep.

Fish

The question of what fish to house in the aquaponic system is important and should be asked early in the design stages of your aquaponics system. The fish you choose to grow will have an impact on the size of your system, as well as specific temperature and water quality requirements. There is much flexibility in choosing fish; however, one rule when it comes to fish selection is that you must use freshwater fish (Bernstein, 2014). This is because many plants cannot survive if they are exposed to saltwater for an extended time. There are a few fish species that are commonly grown in home aquaponics systems.

Tilapia is the most common fish grown in an aquaponic system, both commercially and personally. They are incredibly easy to grow, do well in warm temperatures, and are relatively sturdy when it comes to fluctuating water quality levels that are common in the initial system set up (Bernstein, 2014). A bonus to growing tilapia is that they reach full harvest size in about 9-12 months, which is relatively quick (Bernstein, 2014). A good alternative to tilapia is catfish, as they are a popular choice for those who live in states where tilapia is illegal to grow. They are very easy to raise and grow very quickly, so they share similar characteristics to tilapia.

For those who are more interested in growing fish for fun, there are a few species of fish that thrive in aquaponics systems. Goldfish are an ornamental favorite, as they are very easy to grow, widely available, and relatively sturdy (Bernstein, 2014). People generally choose goldfish in they are not interested in harvesting and eating the fish that they grow. Koi is another ornamental option for those who want to take their fish hobby to the next level. They are hardy fish but require a bit more attention and consideration than a goldfish (Bernstein, 2014). Once koi reach maturity, they can be sold for very high prices, which makes them an attractive fish to grow (Bernstein, 2014). Other species that have been shown to thrive well within an aquaponics system are pacu, guppies, tetras, mollies, carp, silver perch, barramundi, trout, shrimp, and even freshwater lobster (Bernstein, 2014). The type of fish you select is ultimately up to personal preference and the intended use for your fish once they reach maturity.

Plants

There is a large variety of plants that can be grown in an aquaponic system, like the flexibility of fish species one can grow. Virtually any type of plant, vegetable, fruit, herb, and even flowering plants can be grown in an aquaponic system. The type of plants you choose to grow will depend on what type of system you are going to use, as root systems need to be compatible with the system design. Plants with little to no root structure will grow well in a DWC system, while plants like root vegetables will thrive best in grow beds (Bernstein, 2014). It is also important to consider the needs of your plants – the more similar your plant's needs are to the needs of the fish in your system, the better they will grow (Bernstein, 2014). Of course, plant seasons and growing times also play a major role in what you can grow depending on when your system is initially set up.

The one major restriction to plant species that can grow aquaponically are plants that require a pH environment that is drastically above or below the neutral 7.0 pH (Bernstein, 2014). Some examples are blueberries and azaleas, which prefer highly acidic soil, and flower species that prefer very basic soil conditions(Bernstein, 2014). Leafy plants tend to grow best in an aquaponics setting, but it is also possible to grow fruiting plants if you have enough fish (Bernstein, 2014). The best, most common plants that are grown using aquaponics are basil, kale, lettuce, mint, and watercress (Bernstein, 2014). If you have a heavily stocked fish tank that is well established, you can expand to grow beans, cabbage, cauliflower, cucumbers, squash, tomatoes, peas, peppers, and strawberries (Bernstein, 2014).

Setting Up the System

Once you have the structure of the system complete, the next step is setting up the fish tank. This requires much more than just adding water and fish. The tank must be cycled. Cycling is the process of initiating and establishing the biofilter that processes the nitrogen cycle in the aquaponics system. An aquaponic system is fully cycled when there a little to no measurable ammonia or nitrites present in the water, as these chemical compounds are highly toxic to fish. The process of cycling begins when ammonia is added to the system, which can be done either with fish or without fish.

Cycling with Fish

Cycling with fish is the most common, and perhaps easier way to begin the nitrogen cycle in a system tank. It can, however, be stressful because live fish are involved. The basic idea of fish-in cycling is to add the chosen fish species on the day of the initial set up, hoping that they survive the cycling process (Bernstein, 2014). The major challenge with this method is to get the system cycled fast enough that the ammonia levels drop to a non-toxic level before the fish die from suffocation (Bernstein, 2014). It is likely that many of the fish will die, so it is not recommended to start with a fully stocked tank and instead start with less than half (Bernstein, 2014). During cycling, the tank water must be monitored daily for high levels of ammonia using a water testing kit.

During cycling with fish, it is important to monitor pH levels and keep them within 6.8-7.0 closely. A pH lower than 6.8 with slow bacterial reproduction, and a pH higher than 7.0 can lead to higher ammonia toxicity (Bernstein, 2014). In order to keep pH within this range, you must adjust it very slowly, as large pH swings can lead to health problems within the fish (Bernstein, 2014). During cycling, it is typical to find that pH levels are high, so much of the adjusting will be in order to keep pH down (Bernstein, 2014). Once the system is fully cycled, average pH levels will fall, and you will need to switch to raising pH levels (Bernstein, 2014). Cycling with fish is relatively straightforward, but the major drawback is the potential impact it can have on the stock of fish. The fluctuations can be very stressful on the fish and can often lead to premature fish deaths.

Fishless Cycling

Fishless cycling is the second way to cycle a tank and involves adding ammonia from a source other than fish. This technique is advantageous because it reduces the risk of harm to any fish, and you do not have to worry about maintaining a strict pH level (Bernstein, 2014). Cycling without fish also allows for a much higher initial concentration of ammonia, which can greatly reduce the cycling time (Bernstein, 2014). Fishless cycling can take anywhere from 10 days to 3 weeks, compared to the 4 to 6 weeks when you cycle with fish (Bernstein, 2014). Finally, fishless cycling allows for greater control in how much ammonia is added to or present in the fish tank during the cycling process (Bernstein, 2014). If there are particularly high levels of ammonia, you can stop adding ammonia for a short time until the bacteria catch up and begin the nitrogen cycle (Bernstein, 2014). This would not be possible if fish were in the tank.

There are several ways to add ammonia to the system in lieu of using fish. The most common are pure liquid ammonia and crystallized ammonia. Other, more obscure methods that have shown to work are human urine and decaying animal flesh. Whatever your source of ammonia is, there is a basic process that should be followed for fishless cycling. To start, you must add the ammonia to your tank in small amounts until you obtain an initial reading of 2-4 ppm (parts per million) using your water testing kit (Bernstein, 2014). Record the amount of ammonia that brought your tank to this level and begin adding that amount every day until nitrite appears in the tank (Bernstein, 2014). Once the nitrites appear, the daily dose of ammonia should be cut in half (Bernstein, 2014). If, at any point, the measured nitrites exceed 5ppm, you should stop adding ammonia daily until the nitrite lower to 2ppm (Bernstein, 2014).

This process should continue until nitrates appear. At this point, ammonia and nitrites readings should drop to zero, and nitrates levels should be between 5-10ppm (Bernstein, 2014). These levels indicated that it is safe to add fish (Bernstein, 2014). Before you add fish, however, it is important to match temperature and pH levels from their source. Cycling an aquaponics system can be a difficult process that requires a lot of patience and trial and error. Taking the time to establish a secure ecosystem for the stock of fish will take time and effort that will ultimately reward you with a stable, productive system that can be maintained for as long as you want.

Integrating Plants

The final process required is starting and integrating plants into the aquaponics system. There are several ways to get plants fully integrated into your system, such as starting from seeds, using cuttings, and buying plant starts. Starting plants from seeds is the most economical way to begin growing plants for an aquaponics system. The easiest way to do this is by broadcasting seeds or scattering the seeds evenly over the entire growing surface. This is the most common method used when planting in soil, but it is also possible with any media-based system. All you need to do is scatter the seeds over the growing media, and they will naturally fall between the stoned or pebbles and reach the right depth for germination (Bernstein, 2014).

You can also germinate seeds separate from the system using a soil-less medium like vermiculite, vermicompost, or shredder coir (Bernstein, 2014). This can be done in a watertight base tray, where small cups are placed within the water-filled tray (Bernstein, 2014). Each cup should be filled with a moistened growing medium (Bernstein, 2014). Once the cups are set up, you can add 2-3 seeds per cup, and then cover them with a thin layer of additional moist growing medium (Bernstein, 2014). The try should then be covered to keep humidity levels high until the seeds germinate (Bernstein, 2014). The seeds should be checked daily and water should be added to the tray as needed (Bernstein, 2014). Once the seeds have germinated, they will need plenty of light. The seeds can be placed in the aquaponics system once they have sprouted a couple of leaves and have long roots.

Cuttings are a great way to add plants to your system if you have access to plants, as they root very quickly. The cutting should be stripped of leaves, aside from those at the very top of the stem (Bernstein, 2014). After the cuttings are pruned, you can place them directly into the media bed, ensuring that the water meets at least half of the stem (Bernstein, 2014). The cuttings should be covered with some sort of plastic bag to keep humidity levels high while the cutting establishes itself in the growing medium (Bernstein, 2014). Once there is enough root growth, the cutting has been integrated, and you can remove the plastic covering.

Another option is purchasing plant starts from a nursery. To integrate a plant starts into the aquaponic system, that plant should be removed from the pot, and all excess dirt should be shaken off the root system. The roots should be run under water to remove all traces of soil, as well as checked for any pests (Bernstein, 2014). The plant starts can then be placed in the growing medium, with special attention paid to ensuring the roots are making direct contact with the water (Bernstein, 2014).

Plants can be added to a new aquaponic system at any point after the system cycling has begun. Plants can take up nitrogen in all stages of the cycling process but will thrive when the cycling is complete, and the nitrogen cycle is fully established because there are more nutrients available (Bernstein, 2014). When plants are first introduced to a new environment, they focus their energy on establishing a root system (Bernstein, 2014). This can lead to some initial signs of stress like yellowing, dropping leaves, and periods of no growth. This is to be expected (Bernstein, 2014). Adding plants at the start of your system cycling will allow them to establish a root system early on and ensures that they are ready to remove nitrogen-based fish waster from the system as soon as possible.

System Maintenance

One of the best aspects of an aquaponics system is that once they are established, they require very little maintenance compared to other growing systems. With an aquaponics system, there is no weeding, no watering, and no regular fertilization required. Overall, there is less monitoring in general. However, because an aquaponics system is departing from a totally natural system, there are occasional moments where you will need to step in to keep things running smoothly (Savidov and Hutchings, 2005). There are daily, weekly, and monthly maintenance tasks for an aquaponics system that is relatively flexible.

Daily Requirements

The daily requirements for system maintenance include feeding the fish, checking the tank temperature, and checking the pump/plumbing system within the aquaponics system. The fish should be fed at least once a day but is recommended to feed them twice: once in the morning and once in the evening (Savidov and Hutchings, 2005). This will help nourish the fish, as well as provide an opportunity to check on the health of the fish. Checking the tank temperature is a critical part of both system and fish care, as high or low temperatures can have health impacts on the fish and the bacterial colonies in the tank (Savidov and Hutchings, 2005). After feeding the fish and checking the temperature, it is important to check the pumps and plumbing. This will vary by system type and design, but it is necessary to make sure that the water is circulating appropriately through your system.

Weekly Requirements

The weekly requirements for system maintenance are checking pH, checking ammonia levels, replenishing water levels, and checking for insects and pests. Checking pH is vital, as it is arguably the most important indicator of system health. pH is what determined the plant’s ability to absorb nutrients, as well as your bacteria and fish’s ability to survive (Savidov and Hutchings, 2005). Once the system is cycled, pH remains relatively stable, which can lead to a false sense of security that the pH will always be stable. This is not the case, as overtime pH can gradually decrease or increase, and taking weekly measurements can allow you to adjust pH before the system has crashed (Savidov and Hutchings, 2005). The same is true for ammonia levels. As the system recirculates, there will be inevitable evaporation of water that can lead to lower water levels in the fish tank. Topping off water levels once a week keeps it from dropping too low and endangering the fish. With every addition of water, make sure that the water has been sufficiently dechlorinated and that the pH and temperature levels are like that of your fish tank (Savidov and Hutchings, 2005).

Monthly Requirements

The monthly requirements for system maintenance are cleaning out the pump and pipes, agitating any solid waste that has accumulated in the tank, and checking nitrate levels. Cleaning out the pump and pipes prevents any solids buildup, which can affect water circulation (Savidov and Hutchings, 2005). It is also important to agitate any solid waste that has accumulated in the bottom of the fish, as stirring up the solid waste allows the pump to move the waste up into the grow beds (Savidov and Hutchings, 2005). Checking nitrates levels monthly will help determine in the current set up of your system is sustainable. Nitrates are desirable and indicated system health; however, high levels of nitrates can indicate that there are not enough plants to take up the nitrogen that is being released by the bacterial colonies (Savidov and Hutchings, 2005). If you consistently have rising nitrate levels, it is time to add more plants into your system or harvest fish.

Conclusion

Aquaponics, as a method of food production, is a very useful and effective solution to a number of issues that are associated with traditional agricultural practices. Aquaponics is advantageous to traditional agriculture due to the nature of the system design, where plants and vegetables are grown in a soilless medium that allows maximum nutrient absorption. This nutrient rich environment increases yield and speeds up growth time. Perhaps the biggest benefit of utilizing aquaponics as a means of food production is that it is largely self-sustaining and requires very little intervention and maintenance. As this paper has demonstrated, setting up and maintaining a personal aquaponics system is easy to do and widely accessible, with very little financial and time commitments required.

Works Cited

Arco, Lee J., and Elliot M. Abrams. (2006). “An Essay on Energetics: The Construction of the Aztec Chinampa System.” Antiquity 80 (310): 906–18. doi:10.1017/s0003598x00094503.

Bernstein, S. (2014). Aquaponic Gardening . Gabriola Island: New Society Publishers.

Costa-Pierce, Barry A. (1987). “Aquaculture in Ancient Hawaii.” BioScience, vol. 37, no. 5, pp. 320–331., doi:10.2307/1310688.

Diver, Steve. (2005). “Aquaponics-Integration of Hydroponics With Aquaculture”. Attra.

Flavius, B., & Grozea, A. (2011). Increasing the Economical Efficiency and Sustainability of Indoor Fish Farming by Means of Aquaponics. Animal Science and Biotechnologies

Konig, Bettina, Ranka Junge, Andras Bittsanszky, Morris Villarroel, and Tamas Komives. (2016). “On the Sustainability of Aquaponics.” Ecocycles 2 (1). doi:10.19040/ecocycles.v2i1.50.

Morehart, Christopher T. (2012). “Mapping Ancient Chinampa Landscapes in the Basin of Mexico: a Remote Sensing and GIS Approach.” Journal of Archaeological Science 39 (7): 2541–51. doi:10.1016/j.jas.2012.03.001

Nitrogen Transformations in Aquaponic Systems. (2015). Retrieved from Bioenergy Research Group: http://www2.hawaii.edu/~khanal/aquaponics/nitrogen.html

Rakocy, James E., Michael P. Masser, and Thomas M. Losordo. (2006). "Recirculating aquaculture tank production systems: aquaponics—integrating fish and plant culture." SRAC publication 454: 1-16.

Savidov, N., & Hutchings, E. R. (2005). FISH AND PLANT PRODUCTION IN A RECIRCULATING AQUAPONIC SYSTEM: A NEW APPROACH TO SUSTAINABLE AGRICULTURE IN CANADA. ISHS Acta Horticulturae

Timmons, M.B., Ebeling, J.M. (2010). Recirculating Aquaculture (2nd Edition). Cayuga Aqua Ventures, LLC, Ithaca, N.Y.

Wade, N. (1975). New Alchemy Institute: Search for an Alternative Agriculture. *Science*, *187*(4178), 727–729. doi: 10.1126/science.187.4178.727