SUSTAINABLE PRODUCTION OF FOOD

Team Maurick 2

Maurick College

The Netherlands

Researchteam & Writers
Julia Michels
Lina van Oirschot
Kim Pijnenburg
Emma Voeten

Presenters and participants to Water is Life 2018
Julia Michels
Lina van Oirschot

Teacher: Ad Brouwers

a.brouwers@maurickcollege.nl

March, 2018

The aquaponic system

Research team: Julia Michels, Lina van Oirschot, Kim Pijnenburg and Emma Voeten.
Mr. Ad Brouwers (science teacher at Maurick College)
Presentationteam Water is life 2018: Julia Michels and Lina van Oirschot.

Abstract

The aquaponic system uses the plants, the occurring bacteria and the media in which they grow to clean and purify the water in a natural way. This water can be used for like infinity but it has to be refilled sometimes because the water gets lost by evaporation. A maximum of 10 percent of the water of soil-based gardening and even less water than hydroponics is used by the factory. Fish live in the aquarium, they produce ammonium by their poo. When there is too much ammonium in the water the fish die. To prevent that, the water gets pumped out into a bio filter. A lot of bacteria are present in the bio filter that turn ammonium into nitrite, which is still toxic in large quantity . Thereafter the bacteria turn nitrite into nitrate. Nitrate is a nutrient for plants. So after the water gets through the bio filter it will be sprinkled on the plants which take the nitrate from the water and that is how the plants grow. Eventually the water returns to the aquarium and the process starts all over again.

Keywords: *aquaponic system, efficient, bio filter, ammonium, food, fish, sustainable, production*

The main question

How can you produce sustainable food? This paper is divided into different subtopics: mechanical, fish, plants, food, the power of Hydrogen (pH), prevent pollution, oxygen and chemical. All of these elements contribute to sustainable production.

Introduction

For humanity to survive, we have to profoundly change the foundation of human behaviour. We are radically undermining the environment and ecosystem. Water and land shortage will force humankind to develop new crops and agricultural systems in order to reduce detrimental environmental impact. In the light of the ever increasing population and demand for food, the environmental impact must be closely monitored and the agricultural planning with regard to environmental conservation is of great importance.

Using aquaponics, much less water and land will be required to achieve an equal amount of harvested crops, resulting in a pressure decrease on natural resources such as available farm lands and water supplies or a higher output using the same amount of land in order to meet the higher food demand from an increasing population and a cleaner overall environment.

History

The combination of the production of fish and vegetable to an integrated system is not new. Earlier variants of the aquaponic system are the Chinampas of Mexico and the integrated rice paddy systems from parts of Asia. The earliest examples of another branch can be found in South China, Thailand and Indonesia, where the cultivation and farming rice in paddy fields in combination with fish are cited as examples of early aquaponic systems. The ancient Chinese employed a system of integrated aquaculture finfish, catfish, ducks and plants which co-existed in a symbiotic relationship. The ducks were housed in cages over the ponds and the finfish processed the finfish wastes from the ducks. In a lower pound, the catfish live on the wastes that have flowed wrapping from the finfish pounds. At the bottom of the system, the water from the catfish ponds was used for irrigated rice and vegetable crops.

The aquaponics is derived from the idea that fish farmers were thinking of a way how they could increase the production of fish while the dependence of the country, water and other resources were decreased.

Keywords: *earlier variants, South China, Thailand, Indonesia*

Mechanical

It is very important to choose the right place for your system for the most sustainable production of food. The system should be placed in an area where it can catch the optimum amount of sunlight during the day. You can also use a lamp that mimics the sunlight.

It is also very important that there are enough electric outlets for air pumps, which need a shield from water by using a Residual Current Device (RCD). RCD reduce the risks of electrical shocks. It is also necessary to realise that aquaponics can not be replaced very easily because they become very heavy by components like water. Another aspect that should be taken into account is that there needs to be an easily accessible water source. It is necessary to consider where the effluent from the system would go, since the water should be occasionally changed and the filters and clarifiers need to be rinsed. It is also required to feed the fish daily and to frequently monitor the system.

The essential components of an aquaponic unit are:

- a fish tank;
- a mechanical filter;
- a biological filter;
- a hydroponic container.

All these systems use energy to circulate the water while aerating it.
When a square shape fish tank is used, you have to be more active to remove solid waste but it is perfectly acceptable. A see through glass tanks is good because you can view and check the fish and the amount of waste in the tanks easily.
Mechanical filtration is very important for the aquaponic system because it regulates the separation and removal of solid fish waste from the fish tanks. It is also essential to remove these wastes for the health of the system, because harmful gases are released by anaerobic bacteria. If solid waste is left to decompose inside the fish tanks, the waste can clog the system and disrupt the water flow which will cause anoxic conditions for the plant roots. A filter which is usable in an aquaponics system can be located between two separated tanks. This filter catches solid wastes and therefore needs to be rinsed often, but besides that there should also be a clarifier. The clarifier can remove up to 60% of the total removable waste by using the properties of water to separate particles. Since slow water does not move as many particles as water that flows fast, the water has to speed up and slow down so that the particles concentrate at the bottom and can be removed. The water from the fish tanks enters near the clarifier through a pipe, in a swirl clarifier. The circular motion of the water forces the solid waste to move to the centre and bottom of the container, because the water in the centre is slower than the water on the outside. Once this waste is collected at the bottom, a pipe attached to the bottom of the container can be opened regularly, so that the solid waste can flush out of the container and the clean water out of the clarifier goes into the bio filter.

Biological filtration is the conversion of ammonia and nitrite into nitrate by living bacteria. Ammonia and nitrite are toxic to plants, however they do need nitrate to grow. Most fish waste is not filterable using only a mechanical filter, because the waste is dissolved directly in the water and the size of these particles is too small to be mechanically removed. Therefore microscopic bacteria are used to process this microscopic waste. The bio filter is installed between the mechanical filter and the media beds. In some filters they use volcanic gravel, this is the most popular medium to use for media bed units.

The four best qualities of volcanic gravel are that it has a very high surface area to volume ratio, it can be cheap, it is easy to obtain and it is almost chemically inert. Another required component for the bio filtration is aeration.

Nitrifying bacteria need adequate access to oxygen in order to oxidize the ammonia. One easy solution is to use an air pump. Air pumps also help break down any solid waste not captured by the mechanical filter.

Every system requires a selection of Polyvinyl Chloride (PVC) pipes, PVC connections, fittings, hoses and tubes. These provide the channels for water to flow into each component.

Mineralization in terms of aquaponics, refers to the way that solid wastes are processed for plants. Leaving the waste in place for longer allows more mineralization, however if this same solid waste is not properly managed and mineralized, it will block the water flow, consume oxygen and this will lead to anoxic conditions, which in turn leads to dangerous hydrogen sulphide gas production.

Water movement is fundamental to keep all organisms alive in the aquaponics. There are tree commonly used methods of moving water through the system:

- submersible impeller pumps;
- airlifts;
- human power.

But air pumps also keep the water moving.
The water flow dynamics are easiest to understand by following the water flow through the system. Water flows by gravity from the fish tanks through the mechanical and biological filter, this serves for a location for mineralization. After this it flows into the media beds, which host the nitrifying bacteria as well as they provide a place for plants to grow. The water travels down to the sump tank, again by gravity. At this point the water is relatively free of solid and dissolved wastes. Finally this clean water is pumped back into the fish tank, completing the circle.

Keywords: *mechanical filter, clarifier, biological filter, hydroponic container, bio filter, volcanic gravel, air pump, mineralization*

Fish

For fish, nitrite and ammonia are extremely toxic. They are considered toxic above the levels of 1 mg/liter. Under the level of 1mg/liter, nitrite and ammonia are stress factors for fish, because ammonia and nitrite have a bad effect on the fish's health. The level should be close to zero in an aquaponic system. The bio filter is the only one responsible for the transformation of these toxics into a less toxic form.

If you can measure a detectable level this indicates that the bio filters are not functioning well or that the bio filters are not in the right size. If there are warm basic conditions, the ammonia is more toxic. The Total Ammonia Nitrogen (NAT), which is a water test for ammonia, analyzes the types of ammonia in the system. The two ammonia types are un-ionized and ionized.

If there is ammonia or nitrite in the water, you might see some of these symptoms: red streaking on the fish's body, eyes and gills, they might gasp at the surface for air or the fish can also be dead.

A fish's ability to adjust to the water range is low. If you keep the temperature steady in their correct tolerance the fish will be in their optimal conditions. When fish are in their optimal conditions, it supports fast growth, helps reducing the stress level and it lowers the risk of getting diseases.

If you want to have a steady water temperature, you can use water coolers and heaters. If you live in an area where the energy is very expensive this might cost you a lot of money. That is why it is better to have your fish adapted to the local environmental conditions. The farmer has to do research about the temperature range. In general, tropical fish's temperature range is around 22-32 °C and for the cold-water fish the temperature range is 10-18 °C.

To prevent algae growth, the light in the tank should be reduced. But if it is very dark and then suddenly exposed to a lot of light, the fish will feel stress and fear. It is best to have natural light in the tank through shading, this is both good for a low stress level and algae level.

Different fish species have showed successful growth rates in aquaponic units. The fish species that are suitable for aquaponic farming are: silver carp, common carp, grass carp, tilapia, jade perch, barramundi, salmon, catfish, trout, largemouth bass and Murray cod.

When planning an aquaponic facility, it is very important to have appreciation for the importance of the availability of healthy fish from trustworthy suppliers. Some fish species have been introduced to an area outside of their natural habitat, for example the tilapia, catfish and some of the carp species. The introduction of these fish has been through aquaculture. You need to know about the importation of new species. Exotic (non-native) species should not be released into local bodies of water. You should contact a local extension agent for more information about native species and invasive species suitable for farming.

Keywords: *nitrogen, temperature, lighting, fish selection*

Plants

In the aquaponic system you will plant some vegetables, but the plants and fish can only be added after the system completed the cycle. If necessary, the plants can be planted just a bit earlier than the fish, but then the chance of nutrient deficiencies is high, because nutrients take time to reach optimal concentrations. When the fish are added there will follow a spike of ammonia and nitrite. This only happens if the daily ammonia amount you add during the cycle is lower than the ammonia created by the fish.

If the amount of ammonia or nitrite rises above 1 mg/L you have to renew the water.

The main goal is to produce sustainable and high quantity food, so it is important to check very often if the plants, as well as the fish, are doing fine.

Plants have a high chance of getting pests, diseases or fungal. Another problem that appears a lot is that there are not enough nutrients. This happens when the fish did not produce enough waste. You can recognize nutrient deficiencies by poor growth, yellow leaves and poor root development. When this happens, the fish food or bio filter can be increased or the plants have to be removed. Plant health is an extremely important aspect of aquaponics food production. To secure healthy plants the management of pathogens, pest, optimal nutrition and smart planting have to be perfect.

Controlled environments, like aquaponics, are particularly problematic for pests as the closed and safe area without any wind or rain is a perfect place for insects. To prevent diseases it is also vital to select plant varieties that are adjusted to grow in aquaponic systems or which has a higher degree to resist diseases. It is very important to monitor, because it is the foundation of disease and pest management. You have to look for early signs of deviation of the regular growth. When plants have signs, it is necessary to remove the bad part or even the entire crop. The avoidance of soil contamination and the use of tools which are not infected would actually really help the transmission of potential pathogens into the system. Harmful insect pests, like whiteflies or snails, eat and damage the plants. When such a problem appears you have to deal with it, but it is absolutely impossible to use chemical pesticides or insecticides, because they will mean the death for the fish and important bacteria. So you have to look for another way to get rid of or prevent the pests. Some examples for physical, mechanical and cultural options are:

- netting screens, with a mesh size of 0.15 mm to keep out leaf miners. Although the nets are only effective when the plants are very young or even still seeds. But it will not be able to keep the insects out forever, it will just slow the spread.
- physical barriers, between and around the vegetables like paved surfaces. Then again, it is not able to stop the insects.
- hand inspection and removal, by using your hands or steam water to prevent the spread. The steam can kill some insects and other insects will be washed away. But it will cost a lot of time when you just use your hands.
- plant choice, because some plants are more attractive to pests than others. That is why it is recommended to plant different kinds of plants into the system.
- biological controls, because some pesticides are not harmful for fish, plants or bacteria, but only for the pests. For example: Trichoderma, Ampelomices and Bacillus subtilis. They should be applied on the leaves or close by the roots.

The successful production of sustainable food is the result of management strategies to avoid disease spreads that focus on the environmental conditions. Diseases arise in specific areas and periods during the year when the conditions are better.

The activation of some bacterial and fungal diseases only occurs with the presence of surface water, so that is why it is very important to control the relative humidity and moisture. And it is also good against the evaporation of water. A very important aspect is planting densities, because it increases the humidity among the plants. During an outbreak of diseases it is wise to shift to other crops. A good example is basil, because it has more tolerance to the pathogen. It is best to buy seeds or seedlings from a good nursery which can secure disease-free products.

When you are going to plant the seeds you first have to look which plants are clever to plant. It is important to have plant diversity, because if you have only one crop, the chance for serious infestation is higher. You have to stagger plant, so that you can constantly harvest. Plants like tomatoes, basil and coriander can be harvested the whole season.

The roots of the plants have some kind of hairs, which help the absorption process. Moreover, the roots help anchor the plant in the soil, so that the plant will not fall over. Roots are also store extra food for in the future use. The roots preserve 90 percent of the metals which are absorbed by the plants, including iron and zinc.

The stems of the plants are basically the structure of the plant. They are also the plant's plumbing system, because it conducts water and nutrients from the roods to the other parts of the plant. Meanwhile stems also transports food from the leaves to all the other areas.
The seeds of the plant are the reproductive structures and fruits serve to help disseminate these seeds.
Leaves are very important for the water transpiration. Leaves also produce food because they catch sunlight and, through photosynthesis, use it to make food. In the leaves are chloroplasts, which contain chlorophyll. Chlorophyll is an enzyme that uses the sunlight's energy to break apart CO_2 to create glucose. The process needs H_2O and releases O_2. Then at night, the plants use a system called respiration to use the glucose and O_2 to create energy for growth. So you have to make sure the aquaponic system is in a place where all the plants stand in the light.

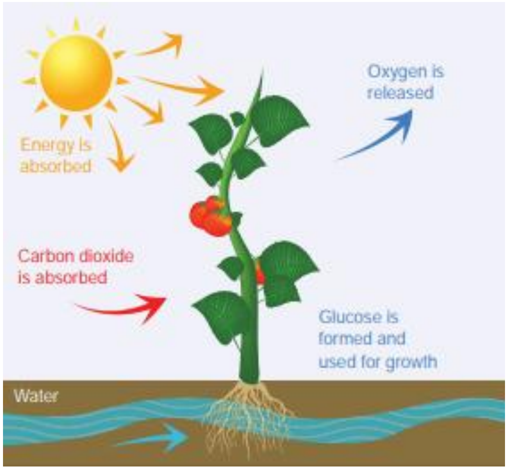

Figure 1: The photosynthesis process
Source: http://www.fao.org/3/a-i4021e.pdf

In addition to these basic requirements for photosynthesis, plans require nutrients, in other words: inorganic salts. These nutrients are needed for the enzymes, for reproduction and also for growth. In aquaponics the fish waste is the source of the nutrients. There are two types of nutrients: macronutrients and micronutrients. The plants need five nutrients in large amounts:

- Nitrogen (N), because it is the base of all proteins and it builds structures, photosynthesis, cell growth and producing chlorophyll. By an overdoses of nitrogen it can cause excess vegetative growth resulting in soft, vulnerable plants.
- Phosphorus (P), for plants it is the backbone of DNA. It is essential for photosynthesis and for the formation of oils and sugars. When there is a lack of phosphorous, the roots can not develop and the leaves look dull green or brown.
- Potassium (K), because it is used for cell signalling from controlled ion flow through membranes. It is needed by the production and transportation of disease resistance, sugars and the ripening of fruits. Without it the fruits will not develop in a correct way. Deficiency manifests as burned spots on the leaves and poor plant vigour.
- Calcium (Ca), because it is the structure component of cell walls and membranes. By a lack of Calcium the new leaves have a different, unnatural shape.
- Magnesium (Mg), is the centre electron acceptor in chlorophyll molecules and is a key element in photosynthesis. Deficiencies can be seen when the leaves are getting yellow in older parts of the plant.

When there is somehow deficiencies you have to add outside nutrients like organic liquid fertilizer.

Feed ration is also a very important aspect. It is a ration based on how many fish food should be added to the aquarium, based on the available area for plant growth. It is also based on what kind of vegetables are planted because fruiting ones require one-third more nutrients than leafy greens. Fruiting vegetables need 50-80 g of fish food per day per square metre and leafy green plants need 40-50 g of fish food per day per square metre. On one square metre can be planted 20-25 leafy green plants and 4-8 fruiting vegetables.

For plants it is vital that the pH is between 6 and 7, so the plants will have access to all the nutrients in the water.

Food

The food that has not been eaten must not be left in the aquaponic system. The leftover food consists of heterotrophic bacteria, which consists of a large amount of oxygen. The dissolved food increases the amount of ammonia and nitrite to a toxic level in a short period. In the end, the uneaten food can clog the mechanical filters, leading to reduced water flow and oxygen-free spots. Normally, fish will eat everything they need in a 30-minute period. After this period you can remove all leftover food to avoid overfeeding.

As mentioned above, the Feed Conversion Ratio (FCR) describes how efficiently an animal turns the food into its growth. It answers the question of how many units of food are needed for an animal to grow one unit. Fish have one of the best FCRs of all animals. In good condition, tilapias have an FCR of 1.4-1.8, which means that they need 1.4-1.8 kg of food to grow 1.0 kg.

Fish needs the right balance of proteins, carbohydrates, fats, vitamins and minerals to grow and be healthy. This type of food is called whole food. Commercially available fish food pellets are very good for small-scale aquaponics, especially at the beginning.

Protein is the most important component to make fish mass. Proteins are the basis of enzymes in all animals. Proteins consist of amino acids, some are made in the body of the fish, but others must come from the food. These are called essential amino acids. Of the ten essential amino acids (arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine), methionine and lysine are often the limiting factors and these must be added in some vegetable-based feeds.

Lipids are fats that consist of high-energy molecules that are necessary for a fish's diet. Fish oil is a common ingredient of fish food. Fish oil has two special types of fats, omega-3 and omega-6, which is healthy for humans. The necessary amount of these lipids in farmed fish depends on the feed used.

Carbohydrates consist of starches and sugars. This ingredient is cheap and provides an increasing energy value of the feed. The starches and sugars also ensure that the food will bound. Unfortunately the fish do not digest carbohydrates very well and much of this energy can be lost.

Vitamins and minerals are necessary for the growth and health of the fish. Vitamins are organic molecules, made by plants, that are important for the development and the immune system function. Minerals are inorganic elements, which are necessary for the fish to make their own body components, vitamins and cellular structures. Some minerals are related to osmotic regulation.

Keywords: *overfeeding, FCR, balance, whole feed, protein, lipids, carbohydrates, vitamins, minerals*

Prevent pollution

It is advised to perform a water test every week to ensure that all parameters are at the optimal level. The most important tests for weekly use are pH, nitrate, carbonate hardness and water temperature, because these results ensure the balance in the system. It is also smart to test for ammonia and nitrite to recognize problems in the unit, but this is not needed on a weekly basis. If you see problems with the fish or the plants, it is best to test the ammonia and the nitrate first. You can keep the results in a log so that you can notice changes.

The Dissolved Oxygen (DO) level tells the amount of molecular oxygen that is in the water and this is measured in milligrams per litre.

The temperature of the water can influence all aspects of the aquaponic system. The average temperature is between 18 and 30 °C. The temperature has an effect on the DO level but also on the toxicity of ammonia: a high temperature ensures less DO and more unionized ammonia.

Keywords: *water tests, DO, water temperature*

PH

Knowing something about pH can be very useful for the regulation of the aquaponic systems. pH is a scale to how basic or acidic an aqueous solution is.

The pH level in general has a very big effect on the aspects of aquaponics, especially on the bacteria and the plants. The correct pH level is between 6 and 7. This range is good for the fish and plants. For most plants, the pH range is usually 5.5-7.5. Most plants prefer mildly acidic surroundings. If the range is not below 7.5 or above 5.5, the plants get a nutrient lockout. This means that the plants can not use the nutrients that are in the water.

The pH level influences the activity of nitrifying bacteria and also their ability to change ammonia and nitrite. Nitrifying bacteria perform good in a pH range of 6-8,5. Usually this kind of bacteria perform better at a higher pH level. Nitrosomonas prefer a pH between 7.2-7.8 and nitrobacter prefer a pH between 7.2-8.2. This is different from the range for aquaponics, which is 6-7. This range is a compromise between all of the different organisms within the ecosystem. If the pH level is below 6, the nitrifying bacteria will experience complications because the bacteria’s ability to switch ammonia into nitrate is weakened in an acidic surrounding. If this happens there is a big chance that the biofiltration is reduced and as outcome the bacteria cut down the switch of ammonia to nitrate. The level of ammonia begins to expand, this leads to a system that is out of balance and is stressful for the other organisms. If you lose bacterial efficiency, you can solve this by having more bacteria, it is required to have bio filters that are sized accordingly. Not only a pH below 6 can create a problem, but also a pH above 8 can become a serious problem for an entire ecosystem, so it is very important to control the right pH level. There are different ways to slightly change the pH level in aquaponic systems.

Lowering pH by using acid:

Water in an aquaponic system normally acidifies because of respiration and nitrification. After some waiting, the pH level usually decreases to the wanted range. But in some cases it is needed to add acid, because the water might have high pH, high carbonate hardness (KH) and the evaporation rate can be high. In these exceptional cases, the water volume to resupply the system raises the pH to a level that is above the ideal ranges and it beats the natural acidification.

Another example for which the addition of acid is necessary, is if the amount of stocked fish is not sufficient to create enough dissolved wastes to drive nitrification and the resulting acidification.

There is a danger when you add acid to an aquaponic system. The danger is very tricky because when you add acid, at first it reacts with buffers and at that moment you can not notice pH change. You can keep on adding acid and you will not see a pH change, only after a while, the buffers will change and then the pH level will drop hugely. It comes as a stressful shock to the system. If it is necessary to add acid, It is better to practice so that you will not make any big mistakes. You can do this by treating your reservoir of the resupply water with acid and then you are going to check the pH level with a digital meter. If you do this it will remove the risk of adding too much acid. If you want to lower the pH you can also use phosphoric acid, H_3PO_4. This is a relatively mild acid. H_3PO_4 is, for plants, an essential macronutrient, but if you use too much it can cause toxic concentration of phosphorous in the system.

Increasing pH by using buffers or bases:

In an aquaponic system, the pH level can drop below 6. In this case you have to add a base or/and increase the hardness of carbonate. The bases that are used regularly are calcium hydroxide ($Ca(OH)_2$) and potassium hydroxide (KOH). They are strong bases and should be used in the same way as acids, add them little by little. Besides these two bases there is also an easier and safer solution, potassium carbonate (K_2CO_3) or calcium carbonate ($CaCO_3$). The two carbonates will increase the KH and the pH. You can choose between different kinds of bases and buffers. You also have to pay attention to the kinds of plants in your system.

For aquaponics, the temperature of water is an influential parameter for bacteria. The best temperature range to grow bacteria and for the productivity is between 17 and 34 °C. If the temperature of the water drops below 17 °C, the productivity of bacteria will decrease. If it drops below 10 °C, the productivity is reduced by 50 percent or more. During winter, low temperatures have a big influence on unit management.

Keywords: *basic, acidic, phosphoric acid, calcium hydroxide, potassium hydroxide, potassium carbonate, calcium carbonate, water temperature*

Oxygen

All the three organisms in the aquaponic system need oxygen to live. Nitrifying bacteria are irreplaceable in the system. They filtrate the water. These important bacteria always need a sufficient level of dissolved oxygen, in other words DO, in the water so that the productivity is high. DO describes the amount of molecular oxygen in the water, measured in mg/litre. The nitrification need oxygen, without DO the reaction stops because the oxygen is the reagent.

The DO is the most important of all the present substances because it has the most impact on the system. When the DO level drops below 2 mg/litre the fish will die. It is also very important to supervise the level of DO in the system. For small-scale aquaponic systems you can rely on the frequent monitoring of plant growth and fish behaviour and to ensure air pumps are constantly working. Oxygen dissolves immediately into the water surface from the atmosphere but in aquaponics, where the productivity is extremely important, the DO level is way too low for the amount of fish and plants. There are two strategies for small-scale aquaponics. One is to use air pump the other is aerators. Aerators produce air bubbles. Without these strategies the system can not get into the process window.

Figure 2: Air pump in the aquaponic system
Source: self-made picture

The optimal level of DO for the fish, plants and bacteria is 4-8 mg/litre.
The water temperature and the DO level have a connection that affects the productivity. When the water temperature rises, the solvability of DO decreases. So cold water holds more oxygen than hot water does. Therefore is it important to use air pump during the hottest times of the year.

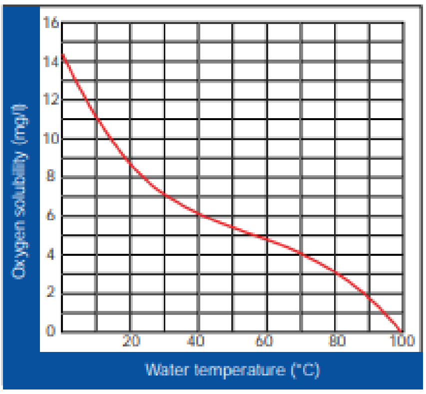

Figure 3: Oxygen solubility in wate
Source: http://www.fao.org/3/a-i4021e.pdf

It is recommended to pump 5-8 litres of air per minute for each cubic metre of water into the system. There should at least be 2 air pumps in the system. It is also important to make sure the water is not pumped too vigorously, so that it will not bother the fish.

When the fish are gasping at the water surface for air, it is a sign that there is not enough oxygen in the system. When this happens, it is useful to have a backup air pump to solve the emergency immediately.

Keywords: *DO level, air pomp, aerator*

Chemical

Nitrogen is an important building material for all life forms. It occurs in all amino acids, which make proteins that are important for many biological processes for animals such as enzyme regulation, cell signalling and the building of structures. Nitrogen is the most important nutrient for the plants.

Although there is so much nitrogen present, it is only present in the atmosphere as molecular nitrogen (N_2), which is inaccessible to plants. Therefore, the molecular nitrogen (N_2) must be changed before the plants can use it to grow. This process is called nitrogen fixation. This is part of the nitrogen cycle. Bacteria can change N_2 by adding other elements such as hydrogen and oxygen and then changing them to new chemical compounds such as ammonia (NH_3) and nitrate (NO_3), which can easily be used by plants.

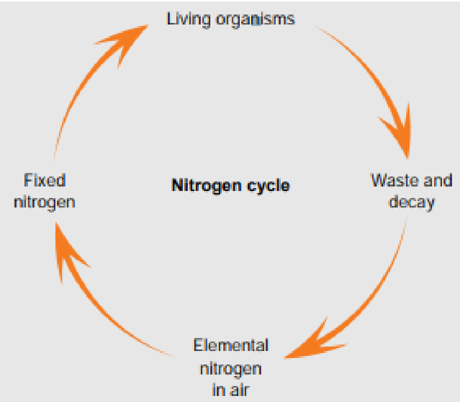

Figure 4: A simple version of the nitrogen cycle
Source: http://www.fao.org/3/a-i4021e.pdf

Animals produce waste such as faeces and urine that consists of a high number of ammonia (NH_3). Other rotting material from nature, such as dead plants or animals, is broken down and converted by fungi and various bacterial groups in ammonia. The ammonia has been converted by nitrifying bacteria. This group of bacteria first converts the ammonia into nitrite compounds (NO_2) and finally into nitrate compounds (NO_3). Nitrogen enters the system through the fish food. The waste of the fish such as urine is usually released in the form of ammonia (NH_3) through the gills.

Nitrogen compounds are nutritious for plants and the basic component of plant fertilizers. All three forms of nitrogen (NH_3, NO_2, NO_3) can be used by the plants, but nitrate is the most accessible. The ammonia and nitrite levels must be close to zero or at most 0.25-1.0 mg/ litre.

Impacts of high ammonia:

Ammonia is poisonous to the fish. Prolonged exposure at 1.0 mg/litre or above is detrimental to the central nervous system and gills of the fish and provides a reduced equilibrium, impaired respiration and convulsions. The damage to the gills can lead to a deteriorating effect of other physiological processes, which leads to a reduced resistance and ultimately to death. The symptoms can be red streaks on the body, lethargy and gasping at the surface for air. The toxicity of ammonia depends on the pH and the temperature. The higher the pH and the water temperature, the higher the toxicity of ammonia.

Ammonia occurs in two forms, namely ionized and unionized. Together they are called the Total Ammonia Nitrogen(TAN). In acidic conditions, ammonia binds with excess hydrogen and becomes less toxic. A low pH ensures a high concentration of H^+ and that is what makes it less toxic. When the pH value is above 7, there are not enough hydrogen ions to ensure that the ammonia becomes non-toxic. This problem is exacerbated in hot water condition. With a high level of ammonia (higher than 4 mg/litre), the amount of nitrifying bacteria decreases. The undersized bio filter is full of ammonia, causing the nitrifying bacteria to die and the amount of ammonia to increase.

Impacts of high nitrite:

Nitrite is also toxic to fish. Problems with fish health can arise with concentrations as low as 0.25 mg/litre. High levels of NO_2 can immediately lead to fish deaths. Toxic levels of NO_2 deteriorate the transport of oxygen within the bloodstream of the fish, which causes the blood to turn brown. You can also notice this effect in the gills of the fish.

Impacts of high nitrate:

Nitrate is much less toxic than the other forms of nitrogen. It is the most accessible form of nitrogen for the plants and the production of nitrate is the goal of the bio filter. Fish can have levels of up to 300 mg/litre, but plants can have a maximum of 250 mg/litre. Higher levels of nitrate can lead to excessive vegetative growth and hazardous accumulation of nitrates in leaves, which is dangerous to human health. It is recommended to keep the nitrate levels at 5-150 mg/litre.

Conclusion:

Plants are able to take up all three forms of nitrogen, but nitrate is the most accessible. Ammonia and nitrite are very toxic to fish and should always be maintained below 1 mg/litre. In a functioning aquaponic unit, ammonia and nitrite are always 0-1 mg/litre and should not be a problem for the plants.

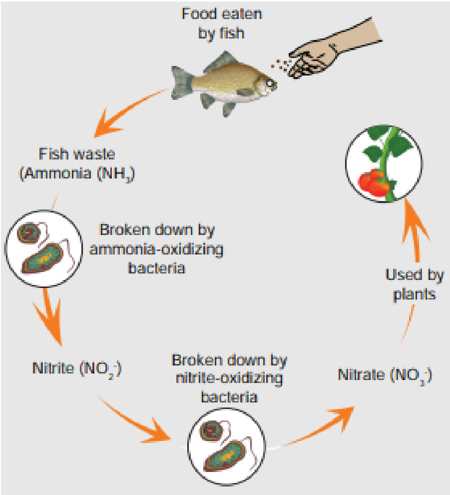

Figure 5: Nitrogen flow chart in an aquaponic system
Source: http://www.fao.org/3/a-i4021e.pdf

Heterotrophic bacteria and mineralization:

The heterotrophic group is an important group of bacteria in the aquaponic system. These bacteria use carbon as their food source and are involved in the decomposition or solid fish and plant waste. 60-70 percent of the food that the fish eat is released as waste. The waste is an organic mix containing proteins, carbohydrates, fats, vitamins and minerals. The heterotrophic bacteria metabolize this waste in mineralization processes, which makes essential micronutrients available for plants in aquaponics. The heterotrophic bacteria and common fungi cause the decomposition of the solid portion of the fish waste. They leave the nutrients in the solid portion in the water. This is an important process because the plants can not absorb nutrients in the solid form.

In the process of the aquaponic system you also have to deal with unwanted bacteria. There are three different groups of unwanted bacteria:

1. *Sulphate reducing bacteria:*

An example of harmful bacteria are the sulphate reducing bacteria. These bacteria are found in anaerobic conditions and they get energy through a redox reaction with sulphur. This process produces sulphide (H_2S) and this is harmful to the fish. These bacteria are part of the natural sulphur cycle. When solid waste accumulates more quickly than heterotrophic bacteria and the associated community can effectively process and mineralize it, results this in anoxic festering conditions that support these sulphate reducing bacteria. This causes problems. The fish produce so much solid waste that the mechanical filters can not be cleaned quickly enough, which makes these bacteria easier to produce their own noxious metabolites. When there is foul odor, such as rotting eggs or sewage, it is necessary to take action. To stop these bacteria, it is smart to supply adequate aeration and to increase mechanical filtration to prevent sludge accumulation.

2. *Denitrifying bacteria:*

A second group of unwanted bacteria are those responsible for denitrification. These bacteria also live in anaerobic conditions. They convert nitrate back into atmospheric nitrogen that is unavailable for plants. These bacteria can increase the efficiency by effectively removing the nitrogen fertilizer. This can cause problems with the large Deep Water Culture (DWC) beds where not enough oxygen is present. A problem can be suspected when the plants give signals of nitrogen deficiencies despite the system being in balance and when there is a low nitrate concentration in the water. Keep an eye on the areas within the DWC canals that are not circulating properly and ensure an increase in aeration with air stones.

3. *Pathogenic bacteria:*

The last group of unwanted bacteria are those that cause diseases in plants, fish and humans. These diseases are treated separately in other parts of the leaves. So it is important that there are Good Agricultural Practices (GAPs) that reduce the risk of bacterial diseases in the aquaponics system.

System cycling and starting a bio filter colony:

System cycling is a term that describes the initial process of building a bacterial colony when first starting any Recirculating Aquaculture Systems (RAS), including an aquaponic unit. This takes 3-5 weeks. The process involves constantly introducing an ammonia source into the aquaponic unit, feeding the new bacterial colony and creating bio filter. The course is measured by monitoring the nitrogen levels. During the cycling process there will be high levels of ammonia and nitrite, which could be harmful for fish. Make sure the bio filter and the fish tank are protected from direct sunlight before you start this process.

Ammonia becomes a food source for the Ammonia Oxidizing Bacteria (AOB). Within 5-7 days after the first ammonia is added, the AOB forms a colony and converts the ammonia into nitrite. The ammonia must be added to the system regularly but cautiously, to ensure that there is enough food for the developing colony without becoming poisonous. After another 5-7 days the nitrite levels in the water rise, which in turn attracts the Nitrite-Oxidizing Bacteria (NOB). When the NOB populations increase, the nitrite levels increase and that causes nitrite to be converted into nitrate.

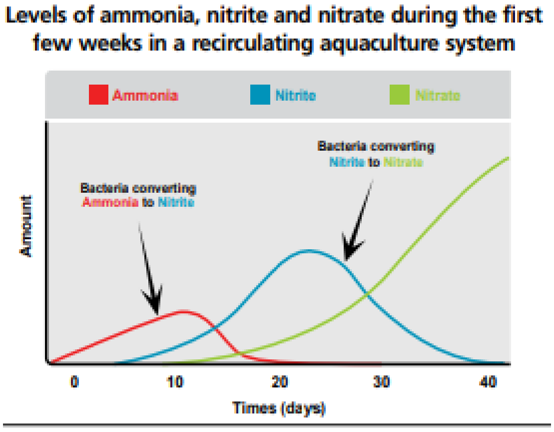

Figure 6: The trends of ammonia, nitrite and nitrate in the water is illustrated in this figure over the first 20-25 days of cycling.
Source: http://www.fao.org/3/a-i4021e.pdf

Keywords: nitrogen, nitrogen fixation, nitrogen cycle, ammonia, TAN, nitrite, nitrate, heterotrophic bacteria, mineralization, sulphate reducing bacteria, natural sulphur cycle, denitrifying bacteria, pathogenic bacteria, system cycling, AOB, NOB

Acknowledgements

We would like to thank Ad Brouwers, our science teacher, for the guidance during our project. We also would like to thank Jonathan Kunst whom we interviewed about the aquaponic system and who helped us a lot to understand how the system works.

References

[1] Consulted at 19-02-2018
https://www.theaquaponicsource.com/what-is-aquaponics/
[2] Consulted at 19-02-2018
http://www.aquaponicssystems.net/
[3] Consulted at 19-03-2018
https://aquaponics.com/home-aquaponic-systems/
[4] Consulted at 29-05-2018
https://nl.wikipedia.org/wiki/Aquaponics
[5] Consulted at 19-03-2018
https://www.friendlyaquaponics.com/
[6] Consulted at 19-03-2018
https://www.friendlyaquaponics.com/free-downloads/
[7] Consulted at 19-03-2018
https://www.mediamatic.net/nl/page/46417/aquaponics-at-mediamatic-fabriek
[8] Consulted at 29-05-2018
http://www.duurzamekost.nl/aquaponics/
[9] Consulted at 19-04-2018
http://www.fao.org/3/a-i4021e.pdf

Appendix

The aquaponic system at Maurick College

Figure 7: Front view of the aquarium

Figure 9: The left side of the system

Figure 8: The left side of the system

Figure 10: In this tank the water level is monitored and here lies the heating element, because we maintain tropical fish in our aquaponic system

Figure 11: Top view of the water tank

Figure 12: This container contains three different purification systems. These ensure that the fish do not get garbage

Figure 13: This container should be able to get the bacteria colony in the system up to standard. If it is set correctly, it should be superfluous

Figure 14: Top view of the container

Figure 15: The air pump in the water

Figure 17: PVC pipe at the right side of the aquarium

Figure 16: PVC pipe at the left side of the aquarium