Deliverables 7.2

Data Bases Development: The Information Technology Platform of the Project

Introduction

Aquaponics, combine the fish farming and growing plants without soil in recirculating aquaculture systems. Lately, these systems have gained popularity, being more sustainable from environmentally and economically point of view, compared to conventional methods.

Obtaining fish and plant production is possible at the same time because the requirements of the fish are somewhat similar to those of plant growth (Rakocy et al. 2006). Waste nutrients from the aquaculture effluent are used for plants growing. The effluent is treated by the plants and returned to the fish rearing units. Generally, the aquaculture effluent offers almost of the nutrients required by plants, if the optimum ratio between daily feed input and plant growing area is maintained.

In an aquaponic system, a wide variety of fish can be grown: tilapia, rainbow trout, channel catfish, koi, Murray cod, Asian Barramundi, mullet, perch, largemouth bass, sturgeons, grass carp and other ornamental fish (Rakocy J. et al., 2010, Endut et al., 2010; Pantanella et al., 2011, Petrea et al., 2013, Petrea et al., 2014, Malik Selek et al., 2017). Lately, some studies were made on shrimps, *Penaeus vannamei*, (Juan F. Fierro-Sañudo et al., 2018), Malaysian prawn or red claw crayfish (Knickerbocker 2013).

Table 1. Advantages of growing in aquaponics systems of some fish species

Fish species	Advantages
Tilapia (*Oreochromis niloticus*)	- fast-growing and efficient at converting food into body mass (feed conversion ratio, ranges from 1.6-1.8:1); - can be grown in high densities; - they quickly adapt to varying conditions (they can survive wider ranges in pH, temperature, and ammonia than many other fish species); - very tasty flesh meat (white meat and a mild taste that consumers prefer).
Rainbow trout (*Oncorhynchus mykiss*)	- fast growing (6 months or so); - trout require a high protein diet compared with tilapia meaning greater amounts of nitrogen in the overall nutrient per unit of fish feed added; - a higher quality of meat and higher price on the market of rainbow trout fillets;
Channel catfish (*Ictalurus punctatus*) African catfish (*Clarias gariepinus*)	- 18-month production cycle; - good fillet yield & dress out % whole fish; - resistant to many diseases and parasites; - given the high tolerance to low DO levels and high ammonia levels, catfish can be stocked at higher densities, provided there is adequate mechanical filtration.

Regarding the most recommended plant species for aquaponic, leafy vegetables are more appropriate (lettuce, basil, spinach, parsley, etc), but good results were also obtained in the case of vegetables such as tomatoes, cucumbers, and peppers, while in the case of fruits the culture period is too higher (90 days or more) and is not economically feasible.

A very popular herb grown in aquaponics systems is Basil (*Ocimum basilicum*), which is a fast-growing herb with a great economic value (due to the essential oils) (Rackocy and Hargreaves, 1993). Basil has low to medium nutritional requirements and prefers warm water (temperature range between 18-30°C, with an optimal of 20-25°C) with pH between 5.5-6.5 pH units and high-light environments (Elia et al., 2014; Moya et al., 2014; Somerville et al., 2014).

In aquaponics is grown at densities of 8-36 plants/m^2 that brought yields of 1.4 to 4.4 for crop cycles of 28 days (Rakocy et al., 2004; Pantanella et al., 2011). According to some authors (Malik Selek et al., 2017), the results in terms of the harvest amount of basil in a square meter can be attributed to several factors, such as different diet composition used for fish feeding, protein level and digestibility of the diet, which may affect the diurnal pattern of ammonia excretion in fed fish, nutrient availability and amount of nutrients in the production system, culture conditions such as water quality, temperature fluctuations, length of growth period, or any combination of all these factors. However, for an optimal growth, all the plants from the aquaponic systems need to have good environmental conditions regarding the light regime, pH, oxygen, carbon, temperature, and nutrients.

In order to assure an optimum performance of an aquaponic system, we must take into considerations all the organisms which are involved in this process: nitrifying bacteria, fish and plants. While nitrifying bacteria play an important biofiltration role (converting toxic fish waste ammonia to nitrate nitrogen, one of the most important mineral nutrients required by plants (Francis-Floyd et al. 2012)), matching the right plant and the right fish species can be a critical factor in terms of suitability for aquaponics production.

Mainly, the selection of plants and fish species should be compatible with the characteristics of each production type (fish and plants) in order to balance nutrient production from fish culture and nutrient uptake by plants. That`s why it is necessary to take into consideration some factors, such as fish stocking density, water temperature and the subsequent nutrient concentration of the aquaculture effluent.

Also, to be effective, an aquaponic system must be exploited continuously. Rakocy et al., 2006, propose three methods of production: the sequential growth of plant biomass, a sequential growth of fish biomass and sequential growth of the plant and fish biomass. Of these, a high degree of popularity is attributed to sequential growth, a method involving the simultaneous growth of aquatic plant species at various stages of development. As they grow, they advance as a position towards the aquaponic unit supply areas. The disadvantages of the method are related to manipulation-induced stress.

From all the fish species presented, the most suitable for growing in aquaponics systems is Nile tilapia (*Oreochromis niloticus*). Tilapia is a warm water species and can tolerate high stocking densities and, therefore became very popular in the aquaponic systems.

Although tilapia can tolerate water temperatures between 14 and 36°C, they are not feeding or growing below 17°C, and die when the water temperature is below 12°C. The ideal range of temperature for tilapia growing is between 25-32 °C.

Regarding the others water quality parameters, tilapia need at least 3 mg L^{-1} concentration of dissolved oxygen, pH between 6.5 and 9 pH units, nitrite concentration below 5 mg L^{-1} and nitrate below 400 mg L^{-1} (Ross at al., 2000; Nandlal S., 2004; DeLong et al., 2009).

Tilapia are omnivorous fish but eat commercial fish food (the feed should contain about 30% protein) and if the proper conditions are assured tilapia grows very fast and may achieve approximately 1 kg in 8-9 months.

Despite all advantages, tilapia may be problematic for the recirculating systems. They breed very fast, even in higher stocking densities, and fry may spread to all parts of the recirculation system. So, they may interrupt the operation of settling tanks or nibble roots in the case of floating raft culture systems. Breeding will also reduce fish production rate and quality.

Another big disadvantage is that tilapias can be aggressive, especially in low densities, because males are territorial. As a solution to this problem, aquaponics farmers prefer to keep only male tilapia, because they to be more profitable as they grow bigger and are more time and energy efficient, while female tilapia tend to waste energy and time due to breeding.

After the right combination of fish and plants was and once the beneficial bacterial populations and efficient cycling are established, fish may be slowly added to the recirculating system.

Once fish are introduced into the aquaponic system, they need a permanent source of food and daily monitoring for illness. Generally, the pelleted fish feed is often used in aquaponic systems. A great importance should be given to fish feeding management, to ensure the fish are getting the needed amount of protein and the feeding intensity and frequency are appropriate for their age. Generally, adult fish are fed around 1% of their body weight per day (BW day^{-1}), and close to 7% BW day^{-1} for juvenile fish.

Feed intensity and feed quality play an important role, because of the influence which can have on the mix and levels of different nutrients in the system. Different diets are appropriate for different growth stages of fish. Diets for juvenile fish are richer in crude protein (40-50 %), while those for adult fish usually have crude protein levels between 30 and 40%. If the feeding intensity and the protein content is too high, the quantity of nitrogen for plants also will be higher. The rate of nitrogen excretion by the fish will affect the biomass and area required for plant production, and the ratio of nitrogen to other nutrients will determine the suitability of the nutrient solution for different types of plant.

Some studies on tilapia suggest that an aquaponic system performed significantly better (Tilapia growth, plant growth) when a quality trout pellet with 45% protein was used compared with a 35% protein catfish feed. It will also normally be the case that the use of a poor-quality feed will result in worse food conversion efficiency and greater production of solids which will have to be removed from the system.

Another important aspect regarding the fish management from an aquaponics system is maintenance of fish health and welfare. The principles of fish welfare and bio-security in responsible aquaculture can also be applied to aquaponic systems. Fish health in aquaponic systems is one of the key factors for their sustainability in aquaculture.

Mainly, the requirements for managing the health status of fish consist in excluding any possibility of pathogens entering in the rearing system, the responsibility to apply prophylactic measures on infectious and parasitic diseases, performing treatment for diseases, respecting a good hygiene at all stages of technological process, mainly at feeding.

Generally, the deterioration of water quality parameters affects fish physiology, growth rate, and feed efficiency, leading to pathological changes and even mortality under extreme conditions (MacIntrye et al., 2008; Person-Le Ruyet et al., 2008). The most important water-quality parameters include ammonia, nitrite, pH, temperature, dissolved oxygen, alkalinity, and hardness. At the very least, TAN, pH, oxygen, and nitrite should be tested once a week, and more often during start-up or when major changes in fish or plant numbers occur (Richard Tyson and Eric Simonne, 2014).

One of the most common causes of fish stress and mortality is higher ammonia concentrations from the water. Poor quality or frequent changes in physicochemical parameters results in a reduction in growth rate, increased mortality, the consequence of stress and an increase in disease incidence. By ensuring a permanent monitoring of the physico-chemical parameters of the water, the danger of triggering pathologies can be avoided. If water quality deterioration is observed, it is advisable to interrupt feeding, increase the flow rate and increase the salinity of the culture water.

Another important factor which can lead to the occurrence of diseases in the aquaponics systems is determined by the quality of fish feed, which directly affects their health. Thus, quoted in the literature are cases of ammonia intoxications, deficiencies in fatty acids, avitaminotic, that clinically exhibits symptoms of inadequacy, low growth rate, low resistance to disease.

The most common sign that fish may be getting sick are: change of behaviour, decreased appetite, darkening or other colour change, unusually slow movement, hanging or swimming in an unusual position (relative to the normal position of the species), swimming abnormally, lying on the bottom, the presence of lesions (such as reddened areas), haemorrhages, ulcers, torn or eroded fins, white eyes, bumps or lumps, and increased mucus production.

Water Chemistry Bases

The water quality in the aquaponic system is the most important aspect to understand because it is the medium through which all essential macro- and micronutrients are transported to both fish and plant biomass (FAO, 2014).

The main water quality parameters that have an impact on fish, plants and bacteria are: dissolved oxygen (DO), pH, temperature, total nitrogen, and water alkalinity. Understanding the effects of each parameter is crucial in the aquaponic systems (FAO, 2014).

Table 2. Ideal parameters for aquaponic systems (FAO, 2014).

	Temp (°C)	pH	Ammonia (mg/litre)	Nitrite (mg/litre)	Nitrate (mg/litre)	DO (mg/litre)
Aquaponics	18-30	6-7	<1	<1	5-150	>5

Dissolved Oxygen (DO)

The DO level describes the amount of molecular oxygen within the water, and it is measured in milligrams per litre. Plants take most of the necessary oxygen from the air via their leaves. Nevertheless, plant roots like a good level of dissolved oxygen in the aquaponic water, because the oxygen has a crucial role in transporting nutrients across the root surface and internalize them. As well, many pathogens operate at low dissolved oxygen levels. It is crucial to ensure adequate DO within the aquaponic system due to the immediate and drastic effects of lower DO concentrations. Fish may die within a few hours if they are exposed to low DO within the fish tanks (FAO, 2014). Oxygen dissolves directly into the water surface from the atmosphere and in natural conditions, fish can survive in such water, but in intensive production systems with higher fish densities, the amount of DO diffusion is insufficient to meet the demands of fish, plants and bacteria. Therefore, supplementation of DO is needed through the use of water pumps and aeration pumps.

Frequent monitoring as often as daily monitoring is required for the DO within the fish tanks units, usually in the morning, before the first feed is applied in the rearing units. Fish species such as carp and tilapia can tolerate DO levels as low as 2-3 mg/litre, however the optimum DO for each organism is situated between the levels 5-8 mg/litre DO. To be noted that DO has a negative correlation relationship with water temperature, therefore when water temperature rises the solubility of oxygen decreases. There are various ways to test dissolved oxygen concentrations and the most reliable one is by using electrical meters with attached oxygen probes.

pH

The pH is the amount of hydrogen ions (H+), is a measure of the ratio of hydrogen ions to hydroxyl ions (OH^-) in the technological water. Water pH measures how acidic or basic the water is on a scale ranging from 1 to 14. The more hydrogen ions, the more acidic the water is. A pH of 7 is neutral, below 7 is acidic and above 7 is basic. pH influences many water quality parameters, such as NH_3 vs. NH_4+ availability and nutrient solubility. pH has a big impact especially on plants and bacteria. Its value determines the availability of macro- and micronutrients that plants use in the growth process. The optimum pH, when the nutrients become readily available is situated in the range 6.0-6.5. pH values above this limit can determine nutrient deficiencies in case of iron, phosphorus and manganese. The bacteria colonies within the system are also influenced by the pH value. Plants prefer pH< 6.5 and nitrifying bacteria perform optimally at pH> 7.5. Nitrifying bacteria reduces its capacity to convert ammonia into nitrate below a pH of 6, which can lead to reduced biofiltration. The nitrification process lowers the pH of the aquaponic system, due to nitric acid production resulted from the liberation of hydrogen ions during the conversion of ammonia to nitrate.

Fish can tolerate a wider pH range and the acceptable range for fish culture is usually between pH 6.5 to pH 9.0. and different fish species require specific pH values. However, if the technological water is very alkaline (>pH 9) it determines ammonia toxicity, which can result in reduced fish growth performance or even death of fish biomass. Aquaculture pH guidelines for warm water fish (such as tilapia) suggest the following: pH<4.0 is acid death point; pH 4.0 – 5.0 there is no production, pH 6.5 - 9.0 is a desirable range for fish production, pH 9.0 - 11.0 gives slow growth, and pH> 11.0 is the alkaline death point.

Carbon dioxide (CO_2) is released into the aquaponic water from processes such as fish respiration and nitrification. CO_2 converts naturally into carbonic acid (H_2CO_3), thus lowering the water pH. The levels of CO_2 increase with high fish stock densities and with increased fish activity (from elevated water temperatures), therefore it is imperative to regulate both variables. CO2 levels should not exceed 20 mg/L because at higher levels the fish become sluggish and cannot absorb sufficient oxygen through their gills.

Plant processes affects can affect water pH. When plants take up nutrients, principally nitrate, they release bicarbonates ions (HCO_3^-), in order to balance the internal electrical charge within their roots. Bi-carbonate scavenges hydrogen ions in water, therefore remover hydrogen ions from the water body.

When controlling the pH in the aquaponic technological water, the entire ecosystem (bacteria, plants and fish) requirements must be taken into consideration, therefore it can be concluded that the ideal aquaponic water is slightly acidic between the range of 6-7.

If the technological water has high pH values periodic acid additions are necessary to lower the pH. Phosphoric acid (H_3PO_4), sulphuric acid (H_2SO_4), nitric acid (HNO_3) have been used to lower the pH however proper safety precautions should be used.

If the technological water is soft or with very low alkalinity and the pH value drops below 6, a base or a carbonate buffer should be added to the water to counteract the natural acidification of the aquaponic unit. The bases most used are potassium hydroxide (KOH) and calcium hydroxide ($Ca(OH)_2$). However, calcium carbonate (CaCO3) or potassium carbonate (K2CO3) can be added, which will increase both the KH and pH. Other inexpensive sources of calcium carbonate can be used such as crushed eggshells, finely crushed seashells, coarse limestone grit and crushed chalk. The choice of the bases and buffers is influenced by the plant species grown in the system. Leafy vegetables are positively influenced by calcium because it avoids tip burns on leaves, while potassium is optimal in fruit plants to favor flowering, fruit settings and optimal ripening. Sodium bicarbonate (baking soda) is often used to increase carbonate hardness in RASs, but should never be used in aquaponics because of the resulting increase in sodium, which is detrimental to the plants.

The pH level needs to be monitored frequently: at least once per week or more frequently. Daily monitoring is suggested as pH generally declines on a time scale of one day as a result of nitrification and respiration.

Temperature

Water temperature influences most of the processes in the aquaponic systems. A general compromise range is between 18–30 °C. Temperature has a direct effect on DO (high temperatures have less DO) and the toxicity of ammonia (high temperatures have more unionized/toxic ammonia). As well, high temperatures may limit the absorption of calcium in plants.

Nitrifying bacteria thrive in higher water temperatures of 22–29 °C, therefore warm-water fish (such as tilapia, common carp, catfish) and warm-water plants (such as okra, Asian cabbages, and basil) should be chosen to match the ambient. Aquaponic systems are more productive if the daily, day to night, temperature fluctuations are minimal. Fish do not tolerate fast changes in water temperature and if the water temperature changes by more than 1.5-2.0°C in less than 24 hours, fish will suffer to some extent. Plants are similar to fish and a good target range for water temperature for most plants is between 14-22°C. Therefore, the water surface itself, in all of the fish tanks, hydroponic units and biofilters, should be shielded from the sun using shade structures.

Total Nitrogen: Ammonia, Nitrite and Nitrate

Nitrogen is required by all life and is part of all proteins. In the aquaculture environment, nitrogen is of primary concern as a component of the waste products generated by rearing fish (Timmons et al., 2002). Nitrogen originally enters an aquaponic system from the fish feed, usually labelled as crude protein and measured as a percentage. The nitrogen waste is mostly in the form of ammonia (NH_3) and is released through the gills and as urine. Ammonia is then nitrified by bacteria and converted into nitrite (NO_2^-) and nitrate (NO_3^-). Nitrogenous wastes are poisonous to fish at specific concentrations, however ammonia and nitrite are approximately 100 times more poisonous than nitrate. Nitrogen compounds are nutritious for plants and are the basic component of plant fertilizers. All three forms of nitrogen (NH_3, NO_2^- and NO_3^-) can be used by plants, but nitrate is by far the most accessible. In an adequate aquaponic unit, ammonia and nitrite levels should be close to zero, or at most 0.25–1.0 mg/litre. The sum of nitrogen from NH3 or NH4+ is called total ammonium nitrogen (TAN). It is recommended to keep TAN as low as possible and below 3 mg/L. The bacteria present in the biofilter should be converting almost all the ammonia and nitrite into nitrate before any toxic accumulation can occur.

- **High ammonia**

Ammonia is toxic to fish and species such as tilapia and carp show symptoms of ammonia intoxication at levels starting from 1.0 mg/litre. Long-term exposure at and above the mentioned level cause's damage to fish central nervous system and gills. The damage of the gills is manifested by red coloration and inflammation on the gills. This leads to improper functioning of physiological processes, which leads to suppressed immune system and eventual death. Other symptoms such as red streaks on the body, lethargy and gasping at the surface for air are noticed in case of ammonia toxicity.

Ammonia toxicity is dependent to pH and temperature. High values of water pH and temperature determine ammonia to become more toxic. The two forms in which ammonia can exist in the water environment is ionized and unionized. The two forms together are called total ammonia nitrogen (TAN).

In acidic conditions, the ammonia binds with the excess hydrogen ions (low pH determines a high concentration of H^+) and becomes less toxic, in the ionized form called ammonium. Nevertheless, in basic conditions (high pH, above 7) the insufficient hydrogen ions determines ammonia to remain in its more toxic state. The activity of nitrifying bacteria declines dramatically at high levels of ammonia. Ammonia can be used as an antibacterial agent, however levels higher than 4 mg/litre inhibits and reduces the effectiveness of the nitrifying bacteria, therefore causing a improper function of the biological filter.

- **High nitrites**

Nitrite is toxic to fish because it disruptes a variety of physiological functions such as: ion regulatory, respiratory, endocrine and excretory processes (Simionov et al., 2017). Concentrations as low as 0.25 mg/litre can pose toxicity to fish. Other fish species such as tilapia can tolerate higher concentrations of nitrites (up to 5 mg/litre). In case of recirculating aquaculture production systems (RAS), Timmons et al. (2002) mentioned that nitrites are highly soluble in water and they represent important water quality parameters that must be monitored and corrected if acceptable limits are exceeded. High levels of NO_2^- can immediately lead to fish deaths. Nitrite is toxic because it affects the blood hemoglobin's ability to transport oxygen. When nitrite enters the bloodstream, it oxidizes the iron in the hemoglobin molecule from the ferrous state to the ferric state. The resulting product is called methemoglobin, which has a characteristic brown color, hence the common name "brown-blood disease".

One of the most important factors influencing nitrite toxicity in fish is the chloride concentration in water and nitrite toxicity decreases with increasing chloride concentration (Simionov et al., 2017). One of the most important factors influencing nitrite toxicity in fish is the chloride concentration in water and nitrite toxicity decreases with increasing chloride concentration. The amount of nitrite entering the blood depends on the ratio of nitrite to chloride in the water, in that increased levels of chlorides reduce the amount of nitrite absorption (Kroupova et al., 2015).

- **High nitrates**

Nitrate is less toxic than the other forms of nitrogen and it is the most accessible form of nitrogen for plants. Fish can tolerate levels of up to 300 mg/litre and some fish species can even tolerate levels as high as 400 mg/litre. High levels (above 250 mg/litre) will have a negative impact on plants, leading to excessive vegetative growth and hazardous accumulation of nitrates in leaves, which is dangerous for human health. It is recommended to keep the nitrate levels at 5–150 mg/litre and to exchange water when levels become higher.

The frequency of measurement should be weekly to monthly for nitrate and nitrite (more frequent if there are problems in supplying DO), but monitoring of TAN should occur on a weekly basis, or more often depending on the environmental conditions, feeding regime and the fish stocking density.

Water hardness

The two major types of hardness are general hardness (GH), and carbonate hardness (KH). General hardness is a measure of positive ions in the water. Carbonate hardness (alkalinity) is a measure of the buffering capacity of water.

GH (Ca^2+, Mg^2+ and Fe+)

General hardness represents the amount of calcium (Ca^2+), magnesium (Mg^2+) and iron (Fe+) ions present in water. It is measured in parts per million (equivalent to milligrams per litre). Both Ca^2+ and Mg^2+ ions are essential plant nutrients. Hard waters are sources of micronutrients for aquaponics. For the fish biomass, the presence of Ca^2+ in the water prevents fish from losing other salts and leads to healthier stocks.

KH (alkalinity)

Alkalinity is the sum total of components in the water that tend to elevate the pH of the water above a value of about 4.5. Carbonate hardness is the total amount of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) dissolved in water. It is also measured in milligrams of CaCO3 per litre. Alkalinity increases if carbonates and bicarbonates are present in the water. As well, substances such as phosphates and hydroxides affect water alkalinity. Water is considered to have high KH at levels of 121–180 mg/litre. Carbonate hardness in water has an impact on the pH level. KH acts as a buffer (or a resistance) to the lowering of pH. Carbonate and bicarbonate present in the water will bind to the H+ ions released by the nitric acid (byproduct of nitrification), thus removing these free H+ ions from the water. Therefore, the pH will stay constant even as new H+ ions from the acid are added to the water. The higher the concentration of KH in the water, the longer it will act as a buffer for pH to keep the system stable against the acidification caused by the nitrification process. The surplus of H+ is balanced with the production of carbonic acid, which is a very weak acid. Each gram of ammonia nitrogen consumes 7.02 grams of alkalinity (as CaCO3) during the nitrification.

The optimum level of alkalinity for aquaponics is about 60–140 mg/litre. It is measured by titration with standardized acid to a pH value of about 4.5 and it is expressed commonly as milligrams per liter of calcium carbonate.

Alkalinity is a key parameter that should be measured once per week to once per month, depending on the size of the aquaponic system and fish stocking density. If alkalinity drops below the recommended values, the addition of calcium carbonate, calcium hydroxide and potassium hydroxide from a base addition tank is suggested.

Macro- and micronutrients

Plant biomass grown in the aquaponic system needs specific nutrients, required by the enzymes involved in photosynthesis, growth and reproduction. These nutrients result from the fish food and fish waste. Nutrients are divided into two categories: macro- and micronutrients. The 6 macronutrients essential for plants are as follows: nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). Micronutrients are only needed in trace amounts but are required in order to fulfill processes such as photosynthesis. The range of micronutrients is much bigger and it includes iron (Fe), copper (Cu), boron (B), manganese (Mn), molybdenum (Mo) and zinc (Zn).

N is a key element in aquaponic systems. N is needed in high amount especially during plant's vegetative growth (young stages) and before fructification; a reduced amount is needed during maturity to avoid difficulties to blooming, fall of young fruits and lower quality of produce. Excess N fertilization will make plants more prone to pests and diseases, due to the tenderness of the vegetable tissues. The main indicator of N deficiency is the yellowing of older leaves, due to its mobility and reallocation capability within plant tissues. In case of N deficiency, N gets transferred from older leaves to new growth areas, which is the reason why N deficiency can be mainly observed in old leaves.

P is essential for the plants 'DNA, phospholipid membranes and for adenosine triphosphate (ATP). It is particularly required in young tissues. Phosphorus is essential for both photosynthesis and the formation of sugars and oils. Deficiencies can lead to poor root growth as energy cannot be transported through the plant in a proper way. Its insufficient supply causes also reddening of leaves due to anthocyanins or stunted growth with dark green leaves and delayed maturity. Tips of leaves might also appear burnt.

K is mainly involved in flower and fruit setting, with the role of cell signaling via controlled iron flow through the plant's membranes. It is an enzymatic activator and supports the synthesis of proteins, carbohydrates and starch. It is also responsible for the transportation of glucose, water uptake and disease resistance. Indicators for a deficiency of potassium appear as burned spots on older leaves or bad plant vigor. Constant potassium addition into the system is recommend, due to its limited availability in the technological water, especially if fruiting plants are grown.

Ca is essential for cell walls and membranes. In plants, it has a high impact on the strength and development of stems and roots. Ca deficiencies are very common in aquaponics and it manifests as tip burn of lettuces and blossom end rot of fruity plants. Ca is transported only through active xylem transpiration, which occurs when the plants are transpiring, therefore a proper ventilation to avoid a high humidity needs to be ensured. Due to limited availability in the aquaponic water, calcium carbonate or calcium hydroxide supplements are recommended to be added in the system.

Mg is a key element in photosynthesis, plant metabolism and is part of the chlorophyll molecule. Deficiencies are hardly found in aquaponic systems, but can be identified if the area between the veins of old leaves turns yellow.

Fe is a micronutrient involved in chloroplasts and the electron transport chain. It is necessary for photosynthesis and deficiencies are often noticed in aquaponic systems. Indicator of Fe deficiency yellowing of all young leaves and vegetative tips turn yellow, or eventually white with necrotic patches all over them. As iron (just like calcium) is a non-movable element, its deficiency can be easily identified when new leaves appear to be chlorotic while old leaves remain green. Iron has to be added into the system up to concentrations of 2 ppm. Iron is normally added in its chelated form, which makes this element easily available to plants. Given the susceptibility to pH it is important to keep the pH below 8 to avoid iron from precipitating and becoming insoluble. The rule of thumb is to add 5 ml of iron per 1 m^2 of plant cultivation area. Too high concentrations of iron do not harm the system but might give a reddish colour to the water.

Plant Bases

Seedlings process

To date, more than 150 different vegetables, herbs, flowers and small trees have been grown successfully in aquaponic systems, including research, domestic and commercial units.

In aquaponics systems there are both the possibility to growth plants seeding and to transplant them into the system till they will achieve maturity, or to put seed directly into the systems, in order to make a continuous production cycle, from seed to seedlings and commercial size plants at the end.

Therefore, in the first case, the seedlings are obtained, in generally, by using soil as a growth substrate. The seeds must be selected first, so that only the fertile ones to be used in the production process, this way limiting the risk of not achieving the targeted seedlings production. After this process, the seeds are generally treated with organic substances in order to accelerate their germination process. This treatment is made inside a container which holds a solution made by diluting the organic substances for germination acceleration. Seeds are places inside that container and are kept sunken into the solution mentioned above, for a number of 1-3days. This process will soften the bark of the seeds, making it more easily to crack during the germination process.

After the process presented above, seeds will be transplanted from the germination solution into the growing substrate. Generally, the substrates are made of soil enriched with a series of nutrients, especially NPK. The rockwool can be also a substrate variant, although it is more fervently used in case of second seeding obtaining variant, which is to be presented. There are also other variants of substrates, more evolved, but also more expensive, like MPS11, developed by Mikskaar.

It is very important, given the fact that the cultivating soil quality is artificially improved with nutrients, that the plant roots to be washed properly before transplanting them into the aquaponics integrated system. Otherwise, the nutrients that remained at the rhizosphere level of the plants can be easily transported into the integrated aquaponics system, fact that can disturb the nutrients balance and also, can represent a threat for fish biomass welfare and condition status, because of improper water chemistry conditions.

Also, it must be mentioned that, before transplanting, the seedlings must be replicated in order to assure a proper develop for each of them.

Regarding the second method of managing the seedling process, it must be mentioned that it presents some risks, as the seeds shell remains inside the system and it will decompose and influence the technological water quality.

Also, there is the risk of getting some diseases like *Pythium* at the rhizosphere level, fact that can compromise the production.

When using this seedling method, there is also the risk of disturbing the system nutrients dynamics, since one of the main purposes of aquaponics is to control water quality. Thus, if seeds are placed into the already functional system, during the germination the bioremediation will be stopped and system must be supplemented with water conditioning equipment.

Also, regarding the atmospheric conditions, in the first case, when seedlings are made outside the integrated system, special micro-greenhouses are used, that can maintain the temperature and humidity at optimal levels. The substrate must be maintained wet, but not soaked in water, the aeration system must be used in order to control the humidity inside the micro-greenhouse. The light is very important, mostly natural light being recommended.

When seedlings are obtained inside the integrated aquaponics system, the atmospherically condition are identical with those used for plants growth. There is a higher susceptibility for things to get wrong, since there is not the possibility to strictly control the atmospheric conditions, as it is in a micro-greenhouse. The lightning system is assured by artificial light. However, it is not recommended to use the same light waves for germination, as for plant growth. One of the advantages of using this technique for obtaining seedlings is related with the fact plants loses during transplantation from micro-greenhouses into the integrated aquaponics system are eliminated.

It must be mentioned that if using rock wool as a growing media, there is not the possibility of reusing it again, ever after washing. In case of soil, this can be reused, but special analysis regarding the level of nutrients encountered at a certain time must be made.

It is important that during the process of obtaining the seedlings, security and safety measurements to be adopted for the prevention of contaminants. Water that is used must be tested in terms of quality and the addition of nutrients, if necessary, must be made by using solutions that are recommended for being used in order to obtain products meant for human consumption. Also, if the desire is to obtain an organic production, using nutrients must be adopted to the international regulations.

Plants growth process:

In order to identify an evolution in the growth process of the vegetable biomass, a series of biometric measurements must be made during the experimental periods. The evolution of the foliar surface, as well as the indicators related to the degree of root and stem development must be observed. The initial biomass of the plant material as well as the final biomass must be determined. Thus, the following calculation formulas must be used [207]:

- ***Growth rate [Wp]*** – difference between final and initial vegetable biomass

$$[W_{veg}] = (Bf_{veg}) - (Bi_{veg}) \qquad [g]$$

where,

Bf_{veg} – final biomass (g);

Bi_{veg} – initial biomass (g).

- ***Leaf area index [LAI]*** – the ratio between total leaf surface and aquaponics unit surface .

$$[LAI] = \frac{L}{P} \qquad [m^2/m^2]$$

where,

L – total leaf surface (m^2);

P – aquaponics unit surface (m^2).

- ***Relative growth rate [RGR]***

$$[RGR] = \frac{1}{\frac{DWi_{veg} + DWf_{veg}}{2}} * \frac{DWf_{veg} - DWi_{veg}}{t} \qquad [g/g/day]$$

where,

DWi_{veg} - initial biomass (dry weight) (g);

DWf_{veg} - final biomass (dry weight) (g);

t – no. of days.

- ***Net assimilation rate [NAR]***

$$[NAR] = \frac{1}{\frac{L1+L2}{2}} * \frac{DWf_{veg} - DWi_{veg}}{t} \qquad [g/m^2/day]$$

unde,

$L1$ – foliar surface at time x (m^2);

$L2$ - foliar surface at time x+y (m^2).

- ***Crop growth rate [CGR]***

$$[CGR] = \frac{1}{P} * \frac{DWf_{veg} - DWi_{veg}}{t} \qquad [g/m^2/day]$$

- ***Average leaf area ratio [Avg.LAR]***

$$[Avg.LAR] = \frac{1}{2} * \left(\frac{L1}{DWi_{veg}} + \frac{L2}{DWf_{veg}}\right) \qquad [cm^2/g]$$

The plant biomass must respect certain quality indicators in terms of micro and macronutrients concentration. Also, it must be mentioned that if a certain essential macronutrient is lacking during plant growth process, this will manifest through series of imbalances that affect directly the plant and also, its growth rate. Plant nutrient deficiencies often manifest as foliage discoloration or distortion. Also, the vegetable biomass must be check first, for signs of insects or disease.

Here are some of the nutrients deficiencies symptoms encountered among the plants:

In case of Ca deficiencies:

- Distorted, misshapen, stunted, hook shaped, leaves.
- New leaves remain green and exhibit marginal necrosis.
- Blackening of edges of leaves
- Low calcium levels can also stunt plant growth and cause plant death.
- Short and stubby roots

The calcium deficiency can be attributed by plants not losing/drawing enough water –poor ventilation or high humidity.

In case of N deficiencies:

- Older leaves will yellow.
- Leaves quickly start drying up
- Stems will yellow and become spindly.
- Growth rate will decrease.

Nitrogen promotes plant growth and improves the quality of leaves. Nitrogen deficiency can be corrected with an application of nitrogen fertilizer. Crop response to fertilization with nitrogen is generally very prompt.

In case of Fe deficiencies:

- yellow and white leaves with green veins
- pale leaves
- no leaves spots

Iron exces: bronzing of leaves with tiny brown spots on the leaves.

In case of K deficiencies:

- Yellowing at the tips and edges - interveinal chlorosis
- Dead or yellow patches develop on leaves.
- Older leaves may look scorched around the edges and/or wilted
- Small spots on the tips – sports turn rusty – folds at tips.

Application of potassium fertilizer will correct a deficiency and, if diagnosed early in the growing period. The excess of K causes deficiencies of Mg, Mn, Zn and Fe by checking their uptake, therefore leaves may start falling.

In case of P deficiencies:

- plant short and dark green – brown/black
- bronze color under the leaves
- plants growth is stunted and leaves become smaller in size
- purple pigment may develop on the back side of the leaf lamina

Excess of P can inhibit the uptake of Zn and its transport within the plant. Long time excess can cause Cu, Mg and Fe deficiencies. Therefore leaf necrosis and shoot death may occur.

In case of Mg deficiencies:

- yellow spots
- elongated holes between veins
- slows growth

Foliar applications of magnesium are effective in emergency situations where immediate response is required to salvage a crop. Excess of Mg can produce Ca and K deficiencies.

In case of Zn deficiencies:

- pale leaves with interveinal chlorosis
- dark spots on leaves and edges
- leaves may be small and distorted with a rosette form

Excess of Zn can inhibit the uptake of Fe.

In case of Mn deficiencies:

- pale color leaves
- veins and venules dark green and reticulated
- plants will be stunted

Excess of Mn will induce brown spots surrounded by a chlorotic zone and circle to the leaves.

In case of B deficiencies:

- discoloration of leaf buds
- breaking and dropping of buds
- inhibits growth

Excess of B will induce leaf tips and margins will turn brown and die.

In case of Mo deficiencies:

- leaves will turn light green/lemon yellow
- spots on leaves, except veins
- sticky secretion under the leaves

In case of Cu deficiencies:

- pale pink between veins
- twisted stems and leaves, and plant lodging

Excess of Cu will induce Fe deficiency.

Therefore, after transplanting, during the plant growth production cycle, the atmospheric parameters and also the light intensity and photoperiodicity must be maintained. Plants biometric measurements must be made in order to obtained the values for the indicators that were previously described. Plants must be observed daily and if any of the signs described above appears, the supplementations with nutrients must be made.

Recirculating Integrated System Operational Management Bases

In order to maintain the integrated aquaponics system at a certain safety and security level and also, to keep it functional during the consecutive production cycles, a proper operational management must be made.

Therefore, this operational management depends mostly on the aquaponics technique used and also, on the technical characteristics of the system.

Thus, when using the DWC, is recommended not to reuse the styrofoam plates after a production cycle ends. Also, the aquaponics units must be periodically cleaned in order to prevent the accumulation of organic matter, which can affect the health and development of the vegetable biomass, as well as its bioremediation potential.

If using NFT technique, the pipes must be verified daily to prevent clogging. Also, the pipes must be washed after the end of the production cycle.

The substrate technique is the most demanding technique in terms of operational management. In this case, the substrate must be washed after each of the production cycle and then activated properly, in order to accelerate the oxidation process of ammonia. When washing, it is recommended that the substrate to be kept sunken into clean water and the washing water to be under a continuously water exchange process, in order to eliminate the accumulated organic matter and the rests of plant root that still remained inside after harvesting.

The pipes must be cleaned, especially in the area of the elbows, because those areas are more expose to organic matter accumulation. Therefore, this can encourage the developed of heterotrophic bacteria and also, they can restrict the flow diameter, thus producing an inconsistent flow rate and changing the flow technical parameters, as hydraulic retention time (HRT) and hydraulic loading rate (HLR).

Mechanical filters must be washed after each production cycle, if auto washing system does not exist as an option, because of the financial aspect. This process must be made also when it comes to biological trickling filters. However, after washing, the bactoballs must be then activated, by using the same process as for aquaponics substrate. It must be mentioned that the activation time depends on the substrate. The bactoballs have the shortest activation time, followed by the aquaponics substrate represented by LECA (light expended clay aggregate) and volcanic rock.

Fish rearing units must be clean periodically and also, the submersion pumps cover. As regarding to the pumps, the must be cleaned inside after each production cycle.

In conclusion, a certain daily operational management must be made in order for the production to growth properly and to respect the safety and security regulations in terms of human consumption. Also, it must be specified that these operations are came together with those that imply respecting the revisions specified in the technical documentation of each used equipment.

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