AWESOME

WATER-ECOSYSTEM-FOOD

DETAILED CHARACTERIZATION OF INNOVATIVE TECHNOLOGICAL SOLUTIONS

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Author(s):	Demet Çekin, Hamis El-Gabry, Mostafa Hassanen, Ricarda Lothmann, Ahmed Saad
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LIST OF ACRONYMS

Abbreviations

AOB: Ammonia-oxidizing bacteria
BPC: Biological Pest Control
CHP: Combined Heat and Power
CPC: Chemical Pest Control
DO: Dissolved oxygen
DWC: Deep Water Culture
EC: Electrical conductivity
FCR: Feed conversion ratio
HIS: High-intensity discharge lamp
HPS: high-pressure sodium lamp
IPM: Integrated Pest Management
IPDM: Integrated Pest and Disease Management
IVA: Integrated Vega Culture
MH: Metal Halide
NFT: Nutrient Film Technique
NOB: Nitrite-oxidizing bacteria
PAR: Photosynthetically Active Radiation
RAS: Recirculating Aquaculture system
SS: Suspended Solids
WHP: Withholding periods after pesticide application
WP: Work Package

EXECUTIVE SUMMARY

Deliverable 5.1 provides an overview of the innovative technological solutions being investigated in the AWESOME test facilities, consisting in the technologies Hydroponics and Aquaponics. The functional and technical requirements of both technologies are described in detail within this report. Special concern is given to the subsystem types commonly used in the field of Hydroponics, which are Deep Water Culture, Nutrient Film Technique, Media-bed system and Sandponics. Subsequently, parameters and influencing factors being decisive for the performance of these innovative systems are characterized. As an example, the optimal parameter ranges for lettuce (*Lactuca sativa*) and Nile Tilapia (*Oreochromis niloticus*) are listed, as these species are commonly used in hydroponic and aquaponic setups and are tested as well in the AWESOME test facilities. As diseases and pests of the host plant depend strongly on the species grown, only the most common ones for these species are presented as well as the corresponding combat mechanisms.

1. INTRODUCTION

Hydroponics and Aquaponics are techniques of plant cultivation and fish farming, which are independent from soil properties and consume significantly less water compared to traditional agricultural practices. While Hydroponics is a soilless plant cultivation method, Aquaponics combines Hydroponics and aquaculture in one system. Both techniques are assumed to have a high potential to tackle water and land shortages due to massive water savings compared to traditional agriculture and to their independence from soil properties. These techniques are particularly interesting for the Mediterranean region because of the combination of favourable temperatures and radiation conditions on the one hand and soil degradation and water scarcity on the other [1–5].
Furthermore, these technologies have more advantages when it comes to productivity levels, which is at least 10 times the productivity of traditional agriculture. This also depends on the system design that allows maximizing the utilization of space. Moreover, these technologies enable year-round production. The closely controlled and monitored environment of the systems (nutrition, temperature, humidity, dissolved oxygen, pH level, light exposure) allows for the harvest of crops daily and consistently all year round [2,6–11].
The advantage and challenge at the same time are that a large number of influencing parameters can and must be set in order to be able to exploit the genetic yield potential of a plant. However, this also comes along with the need for the technical equipment for regulation of these influencing factors. Hence, the main challenges that make it particularly challenging to start a commercial hydro- or aquaponic system are the high initial investments and knowledge about the optimal ranges for those parameters, mainly influencing plant and fish growth. Furthermore, it must be considered that the operating costs are also generally higher than with traditional agriculture, as considerably more energy is required, more measuring and regulating devices are needed and maintenance costs must be taken into account [7,8,10,12].
One of the main goals of Work Package 5 (WP5) is the demonstration of the potential of hydro- and aquaponic systems, especially in terms of productivity maximization per unit water. In order to achieve this, it is crucial to understand and present the technical requirements and the main influencing variables. Therefore, Deliverable D5.1 serves the summary of the general technical requirements of the hydroponic subsystems and the aquaponic setups tested within the AWESOME lab scale facility. It also gives a specific characterisation of the experimental designs used in the AWESOME lab scale facility, and provides an overview of the most important environmental parameters. In Section 2 the technical requirements are reported. It is explained how to create controlled environmental conditions in a greenhouse in general (Section 2.1). It follows a technical description of different Hydroponics subsystems (Deep Water Culture (DWC), Nutrient Film Technique (NFT), media-bed culture and Sandponics) in Chapter 2.2. Finally, in addition to the description of the hydroponic systems as standalone systems, a detailed explanation of the requirements that arise when integrating them into an aquaponic system follows in Chapter 2.3. In Chapter 3, a more detailed characterisation of environmental parameters and how they influence plant and fish growth is given. Special attention is paid to the conditions promoting optimal lettuce and tilapia growth, as these species are cultivated and farmed as well in the lab scale setup as in the pilot scale facility.

2. TECHNICAL REQUIREMENTS

2.1. GREENHOUSE

To exploit the full potential of hydro- and aquaponic systems, the whole environment affecting the systems' performance has to be kept under control. In commercial systems, the plants are therefore grown in greenhouses. A greenhouse offers the possibility to adjust temperature and humidity, and prevents uncontrolled water supply (e.g. precipitation) and can even reduce water losses caused by transpiration due to increased humidity levels. Furthermore, additional technical and electrical elements, such as artificial lighting, can be installed easily and do not need protection from the weather. Usually, the main function is to provide suitable temperatures for plant growth in the greenhouse. Whether heating or cooling predominates, primarily depends on the targeted temperature range depending on the crop - and the climatic profile (especially temperature and radiation profile) of the greenhouse site. In order to be able to set the ideal temperature at any time of the year, both heating and cooling units are required at most locations, even in some regions of the Mediterranean [1].

In order to conduct the AWESOME project laboratory experiments in a controlled greenhouse environment, a greenhouse with a cooling and shading system was constructed in Cairo.

2.1.1. Cooling

It is a well-known phenomenon that greenhouses heat up very quickly, if there is sufficient radiation. A slight to moderate rise in temperature can affect plant nutrient uptake and general plant health. However, the temperature can also rise as high as plants would die off, triggering survival defence mechanisms including early seed production. While in temperate latitudes it is often sufficient to provide simple ventilation in the form of open windows or vents, in hot climates air conditioners are without alternative. Beyond that, shading cloths contribute to cooling besides attenuating solar radiation.

For dry heat, evaporative air coolers are a good option, and respectively, a valid measure for greenhouses in the Mediterranean. The cooling effect results from a simple physical effect. Changing from the liquid aggregate state into the gaseous phase, water draws energy from the air to provide the required latent heat of vaporization. As a result, the air cools down. The less humid the climate, the better the evaporative effect works, as more water can convert from liquid to gaseous state. In greenhouses, cooling pads drained with water are installed at one side of the greenhouse. By blowing air through these pads (wind or fan driven) the water in the pads evaporates. Hence, the temperature drops, while humidity rises. However, this is also accompanied by the fact that within the greenhouse, a temperature gradient is created with the lowest temperature close to the cooling pads [13,14]. Evaporative cooling systems have low energy consumption but require water. The amount of water needed for this purpose might even exceed the demand for irrigation purposes of a flow-through hydroponic system [15]. However, it is important to note that such water is not required to be of the same quality or characteristics as the one used for fertigation purposes. The water in evaporative cooling systems is not used to directly irrigate the

plant. Therefore, a wider range of water quality can be used. The main factors to consider are the biological contents of the water in order to prevent transfer of pathogens to the greenhouse. The second factor is the salinity, which does not directly affect the performance of the system as much as it affects the lifetime of the cooling pads. However, with proper design and treatment, some evaporative systems are claimed to tolerate salinities up to sea water strength [16–18].
The greenhouse at the AWESOME lab scale facility (30 m x 6 m x 2.7 m L x W x H) offers a volume of about 106 m^3 and an area of 180 m^2. To cool down the system, an evaporative cooling system is used. Cooling pads continuously drained with freshwater are installed at one side of the greenhouse (300 x 170 x 20 cm^3). At the other greenhouse side, two fans (1.37 m in diameter) blow air out of the greenhouse, and force fresh air to pass through the cooling pads before entering the greenhouse. To provide temperatures < 25°C (optimal) and < 30 °C (acceptable) the fans run for about 10 hours a day with an air flow of $45.5 \cdot 10^3$ m^3/h. The water consumption for the cooling pads accounts for 0.125 m^3/h (3 m^3/day). The greenhouse is also equipped with a shading cloth elevated vertically above the top of the greenhouse. The shading cloth provides 73% shading in order to attenuate the excess radiation in the summer. The shading cloth is spaced away from the top of the greenhouse, to eliminate heat transfer by conduction from the shading cloth to the greenhouse plastic cover. A side effect is the creation of a relatively isolated layer of air between the cover and the greenhouse further reducing the effects of convective heat transfer, and the overall power output required from the cooling system. The characteristics of the greenhouse and the installed cooling systems is shown in Table 1 and Figure 1.

Table 1 – Properties of the greenhouse and cooling system of the AWESOME lab scale facility.

Parameters	Further
Greenhouse	Quonset greenhouse
Length x Width x Height (max.)	30 x 6 x 2.85 m
Volume	~ 106 m^3
Cover material	Transparent polyethylene plastic, thickness 150 microns,
Shading system	73% shading cloth, 36 x 7 x 3.5 m^2, distance from greenhouse top: 80 cm
Cooling System	Evaporative Cooling
Fan type	Munters
Fan dimensions	137 x 137 cm
Air flow (max. flowrate)	$91 \cdot 10^3$ m^3/h
Number of fans	2
Fan performance characteristics	1.5 HP, 1118.55 W
Pad type	Cellulose material, Honeycomb Corrugation
Pad size	300 x 170 x 20 cm
Water consumption	3 m^3/day for cooling
Pad pump performance characteristics	1/3 HP, 249 W
Pad power consumption	2.5 – 3 kWh/day

Figure 1 – Fans (left) and cooling pad (right) of the convective cooling system at the head sites of the AWESOME lab-scale greenhouse

2.1.2. Heating

The importance of heating for productivity in a greenhouse mainly depends on the preferred temperature range of the crop grown and the climatic conditions of the location. While greenhouses in the Netherlands, for instance, highly depend on active heating, it is less important in the Mediterranean. But still, at most locations, optimal environmental conditions can only be provided safely if both heating and cooling units are available [1].
Conventional active heating techniques are the combustion of natural gas, liquefied petroleum gas, or fuel oil with boilers, water heaters, and unit heaters. Alternative methods are heat pumps, biomass systems, and cogeneration systems. More advanced techniques are solar greenhouses, which use solar radiation not only as a light source but also for heating purposes [19].
The lab scale facility of the AWESOME project in Cairo requires no additional greenhouse heating. Even during winter, solar radiation leads to suitable temperatures within the greenhouse through the use of the passive heat trapping properties of the Polyethylene cover.

2.1.3. Shading

Shading is mainly used to support the aforementioned cooling mechanisms. However, it may also be necessary to reduce the radiation itself, as some plants do not thrive with too much irradiation. Lettuce, for instance, grows quickly at high daily integrals (> 17 mol/m^2/day), but this high growth speed promotes leaf tip burn, which is a physiological disorder caused by calcium deficiency [20]. In the summer, daily irradiation at the AWESOME lab scale site can reach up to 34 mol/m^2/day with a lighting intensity up to 140,000 lux. The shading cloth is important for reducing the amount of light that enters the greenhouse, which lowers the incident irradiance by an amount between 4.97 and 5.58 kWh/m^2 per day (leading to about 42,000 lux within the greenhouse), which in turn is reduced from the heating load and thus from the energy requirements of the cooling system.
The AWESOME lab scale greenhouse is roofed with a shading cloth, in approximately 50 cm distance to the greenhouse enclosure at its closest point on top of the arc (Figure 2).

Figure 2 – Tunnel greenhouse of the AWESOME lab scale facility with a shading cloth for protection against radiation and heat.

2.1.4. Artificial lighting

With light having a major influence on plant growth, supplemental lighting should be considered when operating a greenhouse, especially during the shorter winter days. The lamps used are intended to supplement the natural solar radiation in such a way that optimum conditions are created for the cultivated plant in terms of both duration and radiation intensity.

At present, the most energy efficient lights for greenhouses are high intensity discharge lamps (HIS). These include Metal Halide (MH) and high-pressure sodium (HPS) lamps. MH lamps produce light in the blue spectrum and HPS bulbs emit an orange-red glow. MH lights are best for leafy growth to keep plants compact and are used mainly for controlled environments with little natural sunlight, whereas HPS lights increase flowering and are best for supplementary lighting with natural sunlight, as is the case in greenhouses [21].

Supplemental lights will be assessed for economic viability at the AWESOME lab scale test site. The height of the fixtures is generally dependent on the wattage and the crop type. Fine tuning also considers the distribution profile of the lighting fixture, its rated working plane, and the amount of heat generated by the light source; among several other factors. Generally, low-wattage systems (100 and 250 W) should be located at about 60-90 cm, medium-output systems at 1.23 m, and high-wattage systems (1,000 W and above) at about 1.2–1.8 m [22].

2.2. HYDROPONICS

Hydroponics is a general expression to indicate the soilless cultivation of plants. Depending on the specific way the plants are cultivated, subsystems are differentiated.

Within the AWESOME project, four hydroponic subsystems Deep Water Culture (DWC), Nutrient Film Technique (NFT), Media-bed System, and Sandponics are tested. A detailed description of the applied hydroponic subsystems follows in sections 2.2.1 to 2.2.4.

The parameters adjusted in Hydroponics are summarized in Table 2 in dependence of the subsystem. In all subsystems, parameters like pH and electrical conductivity (EC) are usually measured on a daily basis with handheld devices, as they do not fluctuate much once a system is adjusted properly, and rather change gradually and steadily. Hence, a fully automated procedure is not a requirement for this experiment - albeit favourable for large-scale facilities - and adjustments can be done manually. The EC provides information about the overall nutrient content of the liquid. This is especially true for the DWC and the NFT, as there is no medium that might still hold components that influence the EC when washed out. As with media-bed systems and Sandponics, the roots are not submerged permanently, a sufficient oxygen supply for the roots is ensured. Consequently, artificial aeration is necessary in DWC and NFT systems, as the roots are submerged permanently in this system. Because the plants in the DWC are floating on the nutrition solution, there is no strict requirement for pumping the water in a cycle, as long as aeration is properly designed and maintained. However, cycling the water can be beneficial for waste removal and simplifies the access to nutrients for the roots by ensuring homogeneous mixing of the solution at all times. This is different from the other systems that rely on regular water circulation. In Hydroponics, the recommended ranges for lettuce cultivation are a pH between 5.0 and 6.5 [23], an EC between 1.5 and 2.0 dS/m [24], a dissolved oxygen (DO) concentration between 6 and 8 ppm and water temperature lower than 27°C [21].

One of the biggest advantages of Hydroponics is the saving of water compared to both traditional agriculture and soil cultivation in greenhouses. Current research puts the water savings at up to 90% [2]. This is in contrast to the high initial investment requirement for the technology and the high energy demand resulting in particular from temperature control and pumping [10,25,26]. Since there are hardly any direct comparisons of the subsystems with the soil culture, we will study the subsystems and the soil culture in parallel in the same greenhouse within the AWESOME project. A special focus on water and energy consumption will be placed.

Table 2 – List of parameters to be adjusted in a hydroponic setup depending on the subsystem. The target range of the parameters are adjusted to the needs of lettuce.

Parameter	Target range	DWC	NFT	Media-bed	Sandponics
pH	5.0 - 6.5	Manual	Manual	Manual	Manual
EC	1.5-2.0 dS/m	Manual	Manual	Manual	Manual
DO	6 – 8 ppm	Air stone	Air stone	No	No
water temperature	17 - 27°C	Large-Buffer, less temp. fluctuations	Low-Buffer, high temp. fluctuations	Medium-Buffer, temp. of water largely affected by temp. of media	Medium-Buffer, temp. of water largely affected by temp. of media

air temperature	17-27°C	Provided by greenhouse	Provided by greenhouse	Provided by greenhouse	Provided by greenhouse
Water circulation		No	Continuous water flow	Ebb and flow	Drip irrigation

2.2.1. Deep Water Culture (DWC)

The Deep Water Culture (DWC) is the simplest hydroponic approach, and the system most commonly used in commercial implementation. As illustrated in Figure 3, the plants are placed in holes of a floating raft with the roots permanently submerged in the nutrition solution. Air stones or similar guarantee a sufficient concentration of dissolved oxygen (DO) to prevent oxygen deficiency in the root zone, and the consequent development of anaerobic microorganism populations. Therefore, they are almost constantly in operation. However, it is important to note that the DWC's sensitivity to loss of power/aeration is significantly less than the sensitivity of the aquaculture component seen in Aquaponics. In aquaponic systems, the need of DWC systems for aeration is overshadowed by the need of the Aquaculture component. Usually the aeration required for the fish renders the water sufficiently aerated for the plant roots, thus requiring no further aeration load. On the other hand, in Hydroponic system, it might seem that the aeration is an extra power load required by the DWC systems, as compared to the other types. However, aeration in the DWC can be sufficient to eliminate the requirement of water circulation altogether; provided that the grow bed is properly sized as a buffer tank for nutrients, and that the nutrient mix is adjusted regularly by hand. Therefore, in principle, the aeration can be considered to not be an extra load in DWC systems, but rather the water circulation is the additional cost for hydroponic solution control. It is also worth noting that while other types of subsystems may not require aeration, they are all relatively more sensitive to loss of power since it results in a halt of water circulation which can expose the roots to air and dryness and can cause plant mortality. A DWC system can be set up in glass basins, plastic boxes, concrete basins, and others with water depths ranging from 10 cm to 1 m. Advantages of the simple and reliable system are e.g., the ease of use, simple cleaning and the notably lower risk of plant mortality during power outages. Since the plants are floating and are in continuous contact with the nutrient solution. Power outages can be tolerated up to two weeks, until the plants are affected severely [9]. Usually, this subsystem has constant water flow and needs a small sump tank. Moreover, it is also ideal for warmer tropical climates, being less sensitive to higher temperature and nutrient fluctuations [27]. The disadvantage of this subsystem is the need to level the oxygen content in the water solution via air stone and device for root aeration. When this subsystem is used in Aquaponics, a separate biofilter is needed. Moreover, the system requires large volume of water, takes up a lot space and is labour-intensive [9].

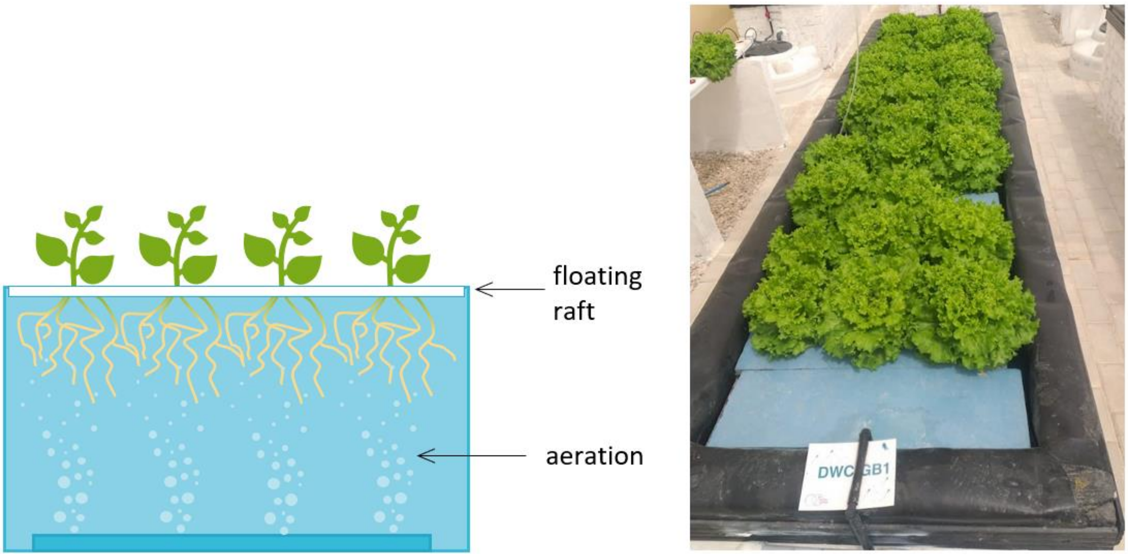

Figure 3 – Schematic figure of a hydroponic implementation using a Deep Water Culture (DWC) (left side) and DWC system in the AWESOME.

Table 3 gives an overview of a DWC system's technical properties used in the AWESOME lab scale facility. This includes the equipment such as a water tank, floating rafts, aeration devices, and pumps to ensure water supply. Furthermore, operational data and parameters are provided for running the system planted with lettuce. A more detailed description of the environmental parameters relevant for properly working hydroponic systems is given in Section 3.

Table 3 – List of hardware components and parameters to be in the DWC system of the AWESOME lab scale facility.

Group	Component/ parameter	Description
Equipment	Water tank	Polyethylene tank, capacity of 500 L.
	Floating rafts	Compressed Polystyrene foam sheets 5 cm thick, with densities between 30 – 40 kg/m^3.
	Aeration device	An air compressor with a capacity of 280 W runs 12 h/d, and uses air stones to distribute it.
	Pump	85 W submersible water pump.
Process data	Water circulation	The water completes a full-loop around the system within 2 hours.
	Water discharge	Water discharge happens only through the following cases: 1. Evapotranspiration 2. Leakage (if any) 3. Discharge in case of severe infection (if any) 4. Periodic discharge of water due to unusable salts build-up (depends on the water source analysis, but can be once every 4 - 6 months)
	Aeration regime	The DO level should remain above 3 ppm for best results
	Power consumption	5.06 kWh/day
	Yield density	1.92 m^2 planting area for leafy vegetables.

2.2.2. Nutrient Film Technique (NFT)

The Nutrient Film Technique (NFT) is a recirculating system for plant cultivation. Within this system, rectangular-section PVC pipes comparable to closed-top rain gutters are used. The plants are placed in baskets into circular recesses in the pipes, with the roots reaching for the pipe's bottom. The pipes are arranged in a slightly sloping position, so water can drain off (Figure 4). Air stones or similar in the water tank are often used to assure optimal oxygen levels, which serves both, sufficient nutrient uptake, and stagnation prevention. A submersible pump provides a shallow flow of liquid in the pipe system to ensure that the roots are kept permanently moist.
The advantage of this subsystem is to have a flexible setup with mobile channels, light weight, stackable, vertical installation of channels one over another. The system components require smaller volumes of water for initial filling than DWC and have light hydroponic infrastructure. The subsystem suits well for vertical farming. On the other hand, if diameters of tubes are small, they can lead to clogging, or insufficient space for root growth [9]. Compared to other subsystems, the initial investment is higher because multiple pipes are required instead of a single growing bed or basin. Also, the water volume tends to fluctuate more strongly due to less water in the system overall and higher evaporation rates. It is assumed, nutrient uptake is not as high as in other subsystems as the contact zone between roots and nutrient solution is lower. When this subsystem is used in Aquaponics, a separate biofilter is needed like in DWC [28].

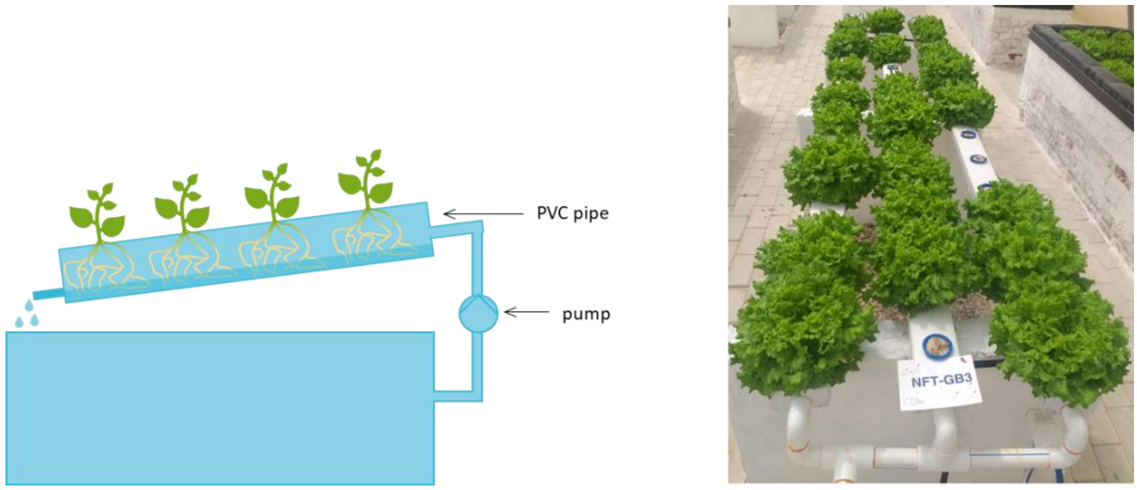

Figure 4 – Schematic figure of a hydroponic implementation using the nutrient film technique (NFT) (left side), NFT system in the AWESOME lab scale facility (right side).

Table 4 gives an overview of the NFT system's technical properties used in the AWESOME lab scale facility.

Table 4 – List of hardware components and process data in the NFT system of the AWESOME lab scale facility.

Group	Component/ parameter	Description
Equipment	Water tank	Polyethylene tank, capacity of 500 L
	NFT channels	PVC pipes for agriculture with dimensions of 10 X 5 X 5 cm
	Pump	85 W submersible water pump.

Process data	Water circulation	The water completes a full-loop around the system within 1.3 hours.
	Water discharge	Water discharge happens only through the following cases: 1. Evapotranspiration 2. Leakage (if any) 3. Discharge in case of severe infection (if any) 4. Periodic discharge of water due to unusable salts build-up (depends on the water source analysis, but can be once every 4 - 6 months)
	Power consumption	1.85 kWh/day
	Yield density	1.92 m^2 planting area for leafy vegetables.

2.2.3. Media-bed System

Different from DWC and NFT, the plants in a media-bed system are planted into inert substrates like coco coir, rice husk, vermiculite, perlite, gravel, peat moss, or expanded clay. The common function of these materials is to provide stability, and to keep the roots humid. Usually, these systems are irrigated using a Flood and Drain approach. The greatest advantage of media-bed systems is combining several functions in one system. They act as mechanical and biological filters and serve mineralization. Solids are removed from the water, broken down and removed.

In this subsystem, nutrients and oxygen are partially held-up in the media maintaining a steady supply, biofiltration in the system is provided through media as it serves as a colonization surface for nitrifying bacteria in Aquaponics (due to its relatively high specific area), hence, there is no need for an extra biofilter [8]. The disadvantage of the subsystem is that it needs a large sump tank, if the Flood and Drain method should be used. This system requires a high hydroponic infrastructure. The maintenance and cleaning of components of the subsystem is difficult. Additionally, water channels of the system can become clogged and consequently, this often can lead to inefficient biofiltration and inefficient nutrient delivery to plants [27]. Figure 5 shows a schematic figure and the picture of the system used in the AWESOME lab scale facility. In this setup irrigation is conducted via drop irrigation.

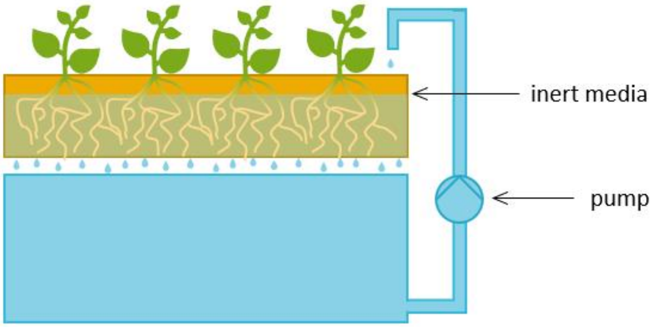

Figure 5 – Schematic figure of a hydroponic implementation using a media bed (left side) and media bed system in the AWESOME lab scale facility with gravel (right side).

Table 5 gives an overview of a Media-bed system's technical properties used in the AWESOME lab scale facility.

Table 5 – List of hardware components and process data in the Media-bed system of the AWESOME lab scale facility.

Group	Component/ parameter	Description
Hardware	Water tank	Polyethylene tank, capacity of 500 L
	Media	Gravel of a smooth surface, without cavities, ranging in size from 3 to 5 cm.
	Pump	85 W submersible water pump.
Process data	Water circulation	The water completes a full-loop around the system within 1.18 hours.
	Water discharge	Water discharge happens only through the following cases: 1. Evapotranspiration 2. Leakage (if any) 3. Discharge in case of severe infection (if any) 4. Periodic discharge of water due to unusable salts build-up (depends on the water source analysis, but can be once every 4 - 6 months)
	Power consumption	1.7 kWh/day
	Yield density	1.92 m^2 planting area for leafy vegetables.

2.2.4. Sandponics

Strictly speaking, Sandponics also belongs to the media-bed systems. The main difference is that sand cannot be considered a completely inert substrate, but is meant to offer supplemental nutrition to the plants. In this system, water supply management is simple and easy to remove plant roots, the system produces less waste than other subsystems and crop yield is quite high in systems [29]. On the other hand, the system is quite new and more knowledge is needed.

The selection of the sand to be used in the system highly influences the results. Different sands from different locations contain different levels of nutrients, and thus has to be taken into consideration. Additionally, a visible consequence of using sand in the system is the vigorous growth of algae on top of the upper layer of the sand. Such algae contribute to overall absorption of nutrients and oxygen, and compete with the plants for such valuable resources.
Figure 6 shows a schematic figure and the picture of the system used in the AWESOME lab scale facility. In this setup irrigation is conducted via drop irrigation.

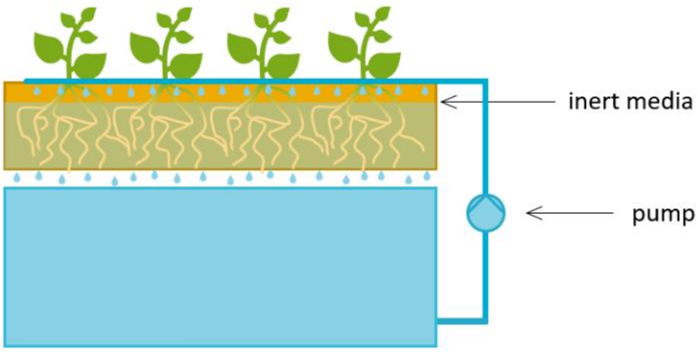

Figure 6 – Schematic figure of a hydroponic implementation using a Sandponics system (left side) and the Sandponics system in the AWESOME lab scale facility (right side).

Table 6 gives an overview of a Sandponics system's technical requirements for successful operation.

Table 6 – List of hardware components and parameters to be adjusted in the Sandponics system of the AWESOME lab scale facility.

Group	Component/ parameter	Description
Hardware	Water tank	Polyethylene tank, capacity of 500 L
	Substrate	fine sand
	Air stone	Not included in the ingredients
	Pump	85 W submersible water pump.
Process data	Water circulation	The water completes a full-loop around the system within 71 hours.
	Water discharge	Water discharge happens only through the following cases: 1. Evapotranspiration 2. Leakage (if any) 3. Discharge in case of severe infection (if any) 4. Periodic discharge of water due to unusable salts build-up (depends on the water source analysis, but can be once every 4 - 6 months)
	Power consumption	0.034 kWh/day
	Yield density	1.92 m^2 planting area for leafy vegetables.

2.2.5. Hydroponic subsystems in comparison

The hydroponic subsystems have a common base but still work differently as described in the previous sections. Table 7 offers an overview of the systems used in the AWESOME lab scale facility, and states out their strengths and weaknesses.

Table 7 – Summary of the components, suitable plants, advantages and disadvantages of hydro- and aquaponic subsystems used in the AWESOME lab scale facility.

Subsystem	Components	Areas of application	Advantages	Disadvantages
DWC	Grow beds, storage tank, aeration system (air stones + air pump), floating platform for plants	Commercial use: optimal for leafy greens, and polyculture, good with vines and vine-like, strawberries, herbs etc.	Simple, reliable, simple cleaning, no risk for plants to die off in case of power outage, inexpensive, good for warmer tropical climates, not sensitive to large temperature and nutrient fluctuations, constant water flow, only small sump tank needed [24].	Levelling of oxygen content in the water solution via air stone, device for root aeration needed [9], separate biofilter needed [25], requires large volume water, takes up much space, labour intensive
NFT	Recirculating system, air stone, air pump, nutrient pump, timer	Flexible setup, flexible harvest methods, optimal for strawberries, good with leafy greens	Flexible setup (mobile channels, light weight, stackable, vertical installation of channels over one another), requires smaller volume of water, light hydroponic infrastructure, suits well for roof farming, nutrient uptake is not high	Clogging of tubes if diameters are small [9], separate biofilter needed [25],it is costly, water is less stable, might be necessary to add more water due to evaporation and as there is less water in the system
Media- Bed	Growth medium is substitute for plants	Soilless cultures like: Flood and Drain systems, optimal for vines and vine-like, good for leafy greens and others	Nutrients and oxygen are saved in the media maintaining a steady supply, biofiltration in the system is provided through media as it serves as substrate for nitrifying bacteria in Aquaponics [8], good biofiltration also in Hydroponics	large sump tank needed, if flood and drain method to be used, high demand for hydroponic infrastructure, maintenance and cleaning is difficult, clogging leads to water channelling, inefficient biofiltration and inefficient nutrient delivery to plants [24].
Sandponics	Sand medium, liquid fertilizer, irrigation cloth	Industrial cultivation, optimal for herb production	Simple water supply management, easy removal of roots, little waste, large-quantity harvest [26].	It is quite a new system; more knowledge is needed.
Standard Practice Cultivation	Soil	All kinds of crops can be produced,	Less infrastructure compared to Hydroponics, natural root environment,	It is difficult to control nutrients in soil cultivation, it is not easy to find suitable

Subsystem	Components	Areas of application	Advantages	Disadvantages
(protected cultivation in greenhouse)		annual, perennial and biennial plants for hobby, industrial or nature	colonized by broad microflora and fungi [25], accepted as "organic way of cultivation"	soil everywhere, fertilisation can lead to environmental pollution or increased salinity in soil, more vulnerable for diseases and host for pests, long time needed for production.

2.3. AQUAPONICS

Aquaponics is the integration of recirculating aquaculture and Hydroponics in one production system. In an Aquaponics unit, water from the fish tank cycles through filters and is finally directed to the plant grow beds, and then back to the fish. In the filters, the fish wastes are removed from the water, first using a solid-waste filter that removes the solid waste and then through a biofilter that processes the dissolved wastes. The biofilter provides a location for bacteria to convert ammonia, which is toxic to fish, into nitrate, which is a nutrient more accessible for plants than ammonia. This process is called nitrification. As the water (containing nitrate and other nutrients) travels through plant grow beds the plants uptake these nutrients, and finally, the water returns to the fish tank purified. This process allows the fish, plants, and bacteria to thrive symbiotically and to work together to create a healthy growing environment for each other, provided that the system is properly balanced [30]. A simplified, schematic illustration is given in Figure 7.

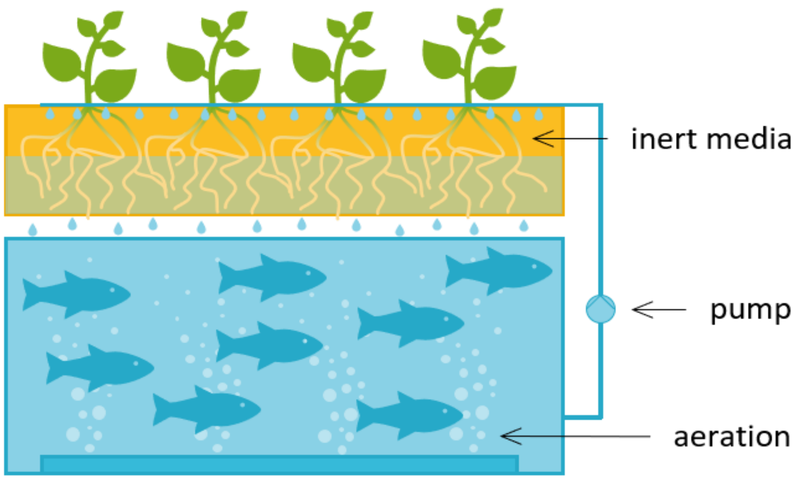

Figure 7 – Simplified aquaponic unit, often used by private users.

The key for balancing an aquaponic system is the consideration of the three populations involved (plants, fish, and microbiome) and how their activities affect each other. The fish primarily act as a source of nutrition for everything down the cycle. The main activity of fish is to convert fodder into fish biomass (measured through Feed Conversion Ratio (FCR)), waste, and a smaller part expended as energy. Thus, the density and feeding regime of the fish controls the size of both, bacteria and plant populations.

The microbiome in an aquaponic system is divided into two main sections; the useful section includes nitrifying bacteria, such as; Ammonia Oxidizing Bacteria (AOB) (e.g. members of the genus Nitrosomonas), and Nitrite Oxidizing Bacteria (NOB) (e.g. members of the genus Nitrobacter). The second section which is either neutral or harmful includes denitrifying bacteria (which includes a wide variety of species, e.g. Bacillus, and some species of Pseudomonas), micro algae (which contribute to withdrawal of dissolved oxygen and nutrients), and others. The objective of a good system design is to provide a favourable environment for the useful bacteria, while maintaining unfavourable conditions for other types. Additionally, some systems are equipped with sterilization measures at specific points to limit the flow of microbiome between the different parts of the system for better control. When the microbiome is provided with sufficient colonization surface and favourable conditions, virtually almost all of the ammonia produced by the fish can be converted to the more useful nitrate cation. A small percentage of ammonia and nitrite can remain in the system, which are usually removed through degassing.

Before the microbiome can perform as expected, the solid waste produced by the fish must be removed. This solid waste, if not removed properly, can lead to anaerobic conditions in some areas of the bottom of the tanks and can lead to growth of unwanted populations of microbiome through its decomposition. Further, this waste can be used as a fertilizer for soil-based agriculture if removed in sufficiently large quantities. It is imperative to maintain a low level of suspended solids in the water before entering the bio-filter, to avoid unwanted competition with the nitrifying bacteria, as well as, other challenges such as clogging and difficulty of cleaning without harming the bacteria in the bio-filter.

With the water cleared from solid waste, and most of the ammonia converted to nitrates, the water is then ready to be used to fertigate the plants. The amount of plants to be cultivated is highly dependent on the amount of nutrients available in the water. But other factors must also be taken into consideration, such as maintaining the pH level within a range that is suitable for all populations involved and that does not affect plant nutrient uptake. Usually, the recommended range is between 6.5 - 7 to ensure proper balance [31].

2.3.1. System components

The aquaponics experiment in the lab scale will run as follows. Each of the subsystems used in the previous hydroponic experiments will be combined with an aquaculture component to form an aquaponic system. The systems will be operated in a closed-loop cycle, whereby each of the tested subsystems are operated in a separate circuit, to be able to evaluate the systems individually. An IVA system (Integrated Vega Aquaculture) will be tested by linking an open loop aquaculture tank with the soil cultivation. Each system consists of the following components:

1. The Aquaculture Rearing Section which is the main component of the aquaponic system. In the lab scale facility, circular fish tanks will be used with a volume of 2,000 L. The water source is fresh water from the Nile through Al-Ismailiyah Canal. The fish species, Nile Tilapia

(*Oreochromis niloticus*) are chosen. The circular tank nature ensures a circular path for the fish in the tank, which provides them with a sense of a larger habitat.

2. The filters, which consist of solid-waste and/ or Biological filters, depending on the type of the hydroponic system to be linked with the aquaculture tanks. Solid-waste filtration will be through passive disc-based techniques (e.g. as opposed to active drum filters) in order to reduce power requirements. Biological filtration will be utilizing Kaldnes design bio-balls for colonization surface with a specific surface area of 600 m^2/m^3.
3. For the agriculture part, the same setup of the Hydroponic experiment will be used to compare the performance of each system (DWC, NFT, Media bed, Sandponics and the control soil cultivation system), under both conditions of nutrient solution (Hydroponic vs. Aquaponic).

The components and volumes used in the aquaponics systems depends on the hydroponic subsystem. An overview is given with Table 8.

Table 8 – Components of the lab scale aquaponics system.

Hydroponic system	Solid-waste filter	Biological filter	Fish tank volume	Water volume in entire system	Plant species	Fish species
DWC	Yes	Yes	2,000 L	3,450 L	*Lactuca sativa*	*Oreochromis niloticus*
NFT	Yes	Yes	2,000 L	2,700 L	*Lactuca sativa*	*Oreochromis niloticus*
Media-bed	No	No	2,000 L	2,700 L	*Lactuca sativa*	*Oreochromis niloticus*
Sandponics	No	No	2,000 L	2,000 L	*Lactuca sativa*	*Oreochromis niloticus*
IVA	No	No	2,000 L	2,000 L	*Lactuca sativa*	*Oreochromis niloticus*

2.3.2. Aquaculture

Aquaculture is the captive rearing and production of fish and other aquatic animal and plant species under controlled conditions. Many aquatic species have been cultured, especially fish, crustaceans and molluscs, and aquatic plants and algae. Aquaculture production methods have been developed in various regions of the world, and have thus been adapted to the specific environmental and climatic conditions in those regions. The four major categories of aquaculture include open water systems (e.g. cages, longlines), pond culture, flow-through raceways, and recirculating aquaculture systems (RAS) [30].

Recirculating aquaculture systems (RAS)

Recirculating aquaculture is a method of rearing fish or other aquatic animals that involves recirculating the water used in the production. The technology is based on the integration of mechanical and biological filters; this technology may theoretically be applied to any aquaculture

species such as fish, shrimp, clams, and other varieties. However, recirculation technology is largely considered in fish farming. Such technology is important to overcome the high demand in production and the scarcity of freshwater that is becoming more severe year by year. This limitation in water gives an advantage to RAS systems over traditional fish farming methods. While traditional fish farming relies on external factors such as temperature of the water source, water quality, oxygen levels, or weed and leaves drifting downstream, the dependency is eliminated either partially or completely in the Recirculating systems based on the design and recirculation rate [31].
Recirculation allows the fish farmer to have complete control over all production parameters, and in this case, it is crucial that the farmer gains the skills to operate and manage the system, adding to the skills of rearing and taking care of the fish.
The control of environmental parameters stabilizes the external conditions that positively affect the fish farming, as it decreases the stress and hence, enhances the growth. These stable conditions produce a predictable and consistent growth pattern, allowing the farmer to accurately estimate when the fish will reach a given stage or size.
Recirculating tanks require more attention than traditional farming methods. It is essential to clean the water regularly in a recirculating system to remove the waste products generated by the fish and to add oxygen to maintain the fish healthy and alive. The main concept of the RAS is that the water runs from the fish tanks' outlets to a solid-waste filter and then to a biological filter before being aerated and carbon dioxide removed and then it is reintroduced to the fish tanks (Figure 8).
One of the major advances of the Recirculating system is the high efficiency of fodder utilization, which decreases the amount of excretion and hence, it decreases the load on the water treatment system. In the best-case scenario of a well operated system, almost all of the feed added will be consumed, with the amount of uneaten feed being kept to a minimum level. The feed conversion rate (FCR), which describes the number of units of feed that is used for every unit of fish biomass produced, is enhanced and increased, resulting in a higher output yield and less impact on the filter system [31].

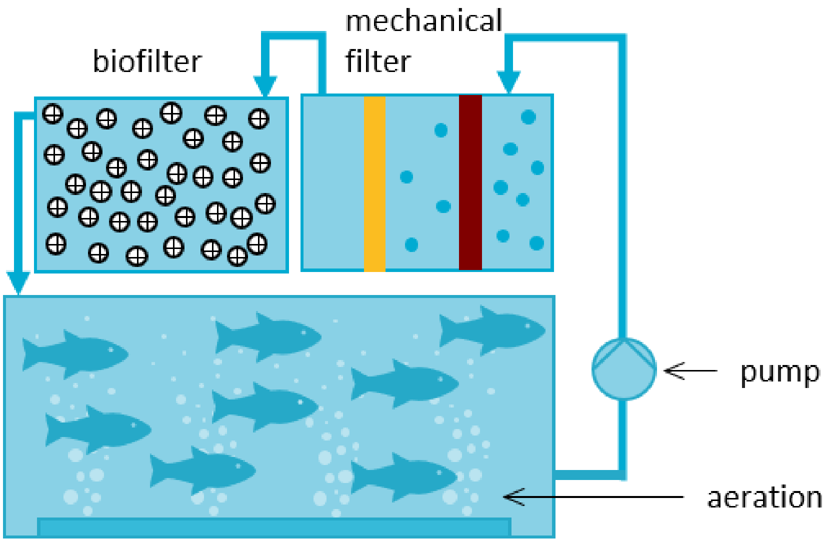

Figure 8 – Components of a simple Recirculating Aquaculture System (RAS)

Fish species in RAS

Recirculating systems are suitable to cultivate different varieties of fish and aquatic animals. It is convenient for both freshwater or marine. Among those types are Tilapia, Catfish, striped bass, crawfish, Blue crabs, Oysters, Mussels. The most common freshwater species in RAS is Tilapia [32].
Hence, the selected fish species for the aquaponics system is **Nile tilapia**, Tilapia is one of the most common farmed fish with a quick growth rate and short production cycle. Tilapia is cultivated in both extensive and intensive setups but in order to be economic and competitive in RAS, production costs must be kept to a minimum [31].
Tilapia in-land growing has been on the rise for the past decades. The global production of Tilapia has reached 6 million metric tons in 2018 (a value of EUR 8 billion), becoming the second most popular species for Aquaculture in the world. Tilapia is also the most farmed fish species in Egypt, which made Egypt second only to China in terms of the global production of Tilapia. The production of Tilapia is increasing in Egypt as it is a widely farmed fish that is easily recognised by customers. The Nile tilapia is the most widely cultured fish in both tanks and ponds [33]. Tilapia have many advantages over other fish species. They are robust fish, which prefer to live in huge groups, making them better suited for intensive farming than other freshwater fish. Tilapia can grow in a variety of pH and temperature conditions. It can also persist a higher amount of ammonia toxicity for longer periods of time compared to other fish, and quickly adjust to changing environmental conditions.
Tilapia are omnivorous; hence, they can feed on a variety of plants, insects, algae, worms, and smaller fish allowing the farmer to potentially avoid using fish feed made from large amounts of fish-meal and fish-oil. Tilapia are warm-water fish, which make them ideal to grow during the summer months, reducing heating costs, and of course, they taste delicious [34].
Concerning the cost benefit, Tilapia are fast growing and efficient at converting food into body mass. Their FCR ranges from about 1.1:1 to 1.8:1, far less than other fish species. Thus, it helps to minimize the feed inputs to the system.

Table 9 offers an overview of parameters and their specifications relevant for Nile tilapia farming, and used in the commercial facilities of Zon Gardens.

Table 9 - Aquaculture data for the aquaponics experiment of the lab scale system.

Parameter	Specification
Species	*Oreochromis niloticus*
Number of fish per 2000 l tank	250 – 100 (dependent from the fish weight)
Fish size (at test start)	20 – 50 g
Stocking density (at test end)	15 kg/m³
Fish feed	Skretting® 30- 32% Protein
Feeding rate	4-5 Times/ Day, 2 - 3% of overall biomass depending on fish size.

Parameter	Specification
Acclimatisation procedure	1. Measure the temperature of the water inside the container/ tank that carries the fish when it reaches the farm. 2. Measure the water temperature inside the fish tank (breeding tank). 3. Do not transfer the fish into the breeding tank if the difference between the temperature in the incoming fry tank and the temperature in the breeding tank on the farm is 5°C or higher. 4. Gradually adjust the temperature by adding water from the farm breeding tank to the incoming fish tank to bring the temperature to a difference of 2-3°C. 5. Now it is ready to transfer the fish to the rearing tanks.

The Nile Tilapia will be reared in circular tanks, this type of tanks was selected for the following reasons:

1. The advantage of creating a good water stream inside the tank, and ensuring new water allocation to all parts of the tank (i.e. elimination of dead zones).
2. The ease of waste removal through the outlet hole.
3. Easy to maintain.
4. Enable operation at a wide variety of rotational velocities to improve fish health and condition, as well as to adjust waste removal rates.
5. Enhance the water flow rate as well as provide a homogeneous culture environment, and uniformed water quality. As a result, the tank's surface area is increased, a protein layer is prevented from accumulating on the surface, and the rate of oxygen exchange is greatly increased [35].

2.3.3. Solid-waste filter

The solid-waste filter is the first phase of filtration in the aquaponic system. Water passes through the solid-waste filter which captures solid waste. This solid waste consists of the suspended particles which are considered to have a range of direct adverse effects in aquaculture such as reducing overall water quality and increasing turbidity, and they are affecting fish health negatively. Suspended particles in intensive RAS largely consist of organic matter basically, originating from the feed, and deriving directly from faeces. Depending on the system design and operation particles tend to accumulate in RAS. The metabolic activity involved in converting fish feed to fish flesh produces waste products. These consist of suspended solids (SS) and dissolved nutrients. Suspended solids amount to approximately 25% of the feed used, on a dry matter basis [31]. A sand filter, for instance, does not consume power directly as it is a passive device. However, due to the pressure loss it causes in the water cycle, it consumes energy indirectly through requiring higher energy from the pump. In general, a sand/gravel filter will cause a pressure drop of 1 - 2 bar, and therefore consume the corresponding energy depending on water flow rate.

2.3.4. Biological filter

The Biological filter is an important component of the Aquaponics system and a crucial element to its success. It is important to be properly sized and maintained in order to sustain the efficiency of any Aquaponics system. The biological filter is the second filtration step after the solid-waste filter, which does not remove all of the organic materials; the smallest particles, as well as dissolved substances like phosphate and nitrogen, will pass through. Phosphate is a non-toxic inert material, while nitrogen in the form of free ammonia (NH_3) or dissolved ammonium (NH_4^+) is poisonous and must be converted to harmless nitrate in the biofilter. The breakdown of organic debris and ammonia in the biofilter is a biological process carried out by heterotrophic bacteria, which consume oxygen and oxidise organic materials, creating carbon dioxide, ammonia, and sludge. Ammonia is converted to nitrite, which is then converted to nitrate by nitrifying bacteria [31].
Bacteria are a crucial and pivotal aspect of Aquaponics, serving as the bridge that connects the fish waste to the plant fertilizer. This biological engine removes toxic wastes by transforming them into accessible plant nutrients. The nitrifying bacteria convert the fish waste, which enters the system mainly as ammonia, into nitrate, which is fertilizer for the plants. This is a two-step process, and two separate groups of nitrifying bacteria are involved. The first step is converting ammonium to nitrite, which is done by the ammonia-oxidizing bacteria (AOB). These bacteria are often referred to by the genus name of the most common group, the Nitrosomonas. The second step is converting nitrite to nitrate is done by the nitrite-oxidizing bacteria (NOB). These are commonly referred to by the genus name of the most common group, the Nitrobacter. They are gram negative bacteria, ranging between 0.6 and 4.0 microns in length. They are obligate aerobes and cannot reproduce or convert ammonia or nitrites without oxygen. The nitrification process occurs as follows:

1. AOB bacteria convert ammonia (NH_3) into nitrite (NO_2^-)
2. NOB bacteria then convert nitrite (NO_2^-) into nitrate (NO_3^-)

Nitrification and therefore, healthy bacterial colonies are essential to a functioning aquaponic system. Nitrifying bacteria are relatively slow to reproduce and establish colonies, requiring days and sometimes weeks, and hence, the patience of the farmer is one of the most important management parameters when establishing a new aquaponic system [30].
Many aquariums and aquaponic systems have failed because too many fish were added before the colony of bacteria was fully developed. There are several other key parameters to support nitrifying bacteria. Generally, bacteria require a large, dark location to colonize with good water quality, adequate food and oxygen. Often, nitrifying bacteria form a slimy, light brown or beige matrix on the biofilter, and have a distinctive odour that is difficult to describe, but does not smell particularly foul which could indicate other microorganisms [30].

2.3.5. Hydroponic subsystem

Hydroponics systems (DWC, NFT, Media bed, and Sandponics) will be connected to a separate fish tank in a closed loop cycle in the Aquaponics lab scale experiment. Not all of the systems will include filters (mechanical and biological) in order to better measure their performance based on their characteristics. In a Sandponics system, for example, water will flow directly from the fish tank to the grow bed after passing through a sump only, as the sand will act as both a mechanical and biological filter. The IVA follows a different mechanism. An open loop cycle is used in this scenario. Instead of recirculating the water, the fish waste water is used untreated to irrigate and nourish the plants in the soil cultivation without getting back to the fish tanks.

3. ENVIRONMENTAL FACTORS

3.1. AIR TEMPERATURE

Temperature directly affects the plant growth performance. The higher the temperature, the faster are the chemical processes in the plant. Chemical processes are mostly regulated by enzymes in plants and the processes perform optimally at a narrow range of temperature. Temperatures below and/or above the optimal range can lead to abortion or reduction of the enzyme activity. Consequently, plants are stressed, and plant growth is reduced and eventually, plants may die [21]. The temperature should be maintained at an optimal range. Within the AWESOME lab scale facility, all experimental setups are performed in a greenhouse at 15-35°C.

Tip burn is a physiological disorder of lettuce, which is an effect of high temperature and limits the production of high-quality crops. The increased temperature is correlated positively with the resulting leaf area of plants. This is due to increased photosynthesis per unit leaf area, water uptake and translocation of plant nutrients. Hence, the lettuces have a rapid growth rate. The tip burn of the lettuce does not only arise from high temperature, but also from environmental factors such as relative humidity, long light period, low calcium levels, low pH, and unfavourable cation balance [36].

The air temperature is important for aquaculture only if it might influence the water temperature.

3.2. WATER TEMPERATURE

The water temperature should not be higher than 27°C for lettuce growth in both hydroponic and aquaponic systems. The water temperature directly affects the nutrient uptake. A high or low temperature is a stress factor which can negatively affect fish growth and development in fish rearing ponds in aquaponic systems [21].

The optimum water temperature to cultivate Nile Tilapia is within the range of 21-35°C, for Aquaponics the range is smaller due to the plants' requirements and ranges from 21 to 29°C. Tilapia requires heating in winter to have an optimum growth rate, as the lower the temperature the slower the growth of Tilapia. Tilapia will dramatically reduce its feeding activity and overall activity below 21°C and will be susceptible to high mortality rates below 15°C. Thus, heat regulation must be utilized to ensure continuous operation and growth during the winter.

The first step in controlling the heat of the water is the passive cover. The rearing area is completely enclosed in a greenhouse, which helps keep the temperature above 16°C at all times. Additionally, in particularly cold winters, an additional cover can be added on top of the fish tanks to provide extra insulation, bearing in mind that an opening must be present to allow for degassing.

Active heating is commonly used for high efficiency and commercial production. In this case, water is artificially heated using an energy source (electricity, fossil fuel, renewables) to intermittently pump heat into the system whenever the temperature drops from the optimum operating range. The use of passive methods (insulation) with this active method is of key importance for energy efficiency.

3.3. LIGHT

A major factor influencing plants' growth performance is light. Accordingly, growth can be strongly influenced with artificial lighting. The essential variables here are the duration of lighting, the wavelength and the intensity of the light. The growth of many plants is connected to the circadian rhythm, which basically is the duration of day and night during the day. Trees losing their leaves in autumn is caused by the dependency from this rhythm, for instance. Hence, with artificial lighting, plants can be grown year-round under optimal radiation.

For lettuce, the optimal light intensity is 17 μmol/m²/s of photosynthetically Active Radiation (PAR) with 16:8 L:D photoperiod [37,38]. The daily integrated PAR can be achieved by supplementing the solar PAR with that from 400 W high pressure sodium (HPS) lamps or metal halide lamps (HS). On extremely bright days (when daylight lasts longer than 16 hours), this solar PAR value can be reduced by deploying a shade cloth, as high light intensity leads to tip burn at lettuces [36].

Light intensity or daily light integral play a great role on the concentrations of nitrate, sugars and other metabolites in several green leafy vegetables including lettuce. While benefiting from solar natural light for long days, during short, dull days of winter months, supplementary lighting should be used to provide additional intensity of light and to extend the day length. During seasonal growing in long summer days, the light intensity can be reduced by using a shade net from the outside roof of the greenhouse [21].

With light being of subordinate importance in aquaculture, different from plant cultivation, commercial Aquaponics systems usually use the natural day and night cycles. Nevertheless, there is already research indicating that long photoperiods enhance the growth of Tilapia [39,40].

3.4. RELATIVE HUMIDITY

The relative humidity affects the transpiration rate of plants. High relative humidity results in a decrease water transpiration from the plants in greenhouse, which causes less transport of nutrients from roots to leaves and less cooling of the leaf surfaces. High humidity can also lead to plant disease with bacteria or especially fungi. E.g., high relative humidity encourages the growth of botrytis and mildew [22]. Relative humidity should be minimum 50% and no higher than 70% in greenhouse [21].

According to current knowledge, humidity does not play a special role in aquaculture, only the evaporation rate is influenced by humidity.

3.5. CARBON DIOXIDE (CO_2)

The CO_2 concentration directly affects the amount of photosynthesis on the plant growth. In open field cultivation, outdoor CO_2 concentration is around 390 ppm. In an enclosed greenhouse,

atmospheric CO_2 content will decline during the day due to photosynthetic activity (absorption of CO_2) and will increase at night as plants respire (release of CO_2). Frequent ventilation of the greenhouse and air mixing within the plant canopy can moderate this cycling of the CO_2 content [41]. Plants in a closed greenhouse during a bright day can deplete the CO_2 concentration to 1,000 ppm. The supplement of CO_2 concentration to 1,500 ppm encourages plant growth in the greenhouse, if the light is available during a bright day. Heaters in winter can provide carbon dioxide but it is not recommended, because heaters often cause air contaminants, which slow down the lettuce growth [21].CO_2 supplementation is particularly challenging in systems equipped with an evaporative cooling setup since the open-loop nature of the air current requires enormous amounts to be supplied into the air, which will then be carried out to the atmosphere increasing the carbon footprint of the greenhouse. Thus, CO_2 supplementation is limited to air-sealed applications.
For fish keeping, the CO_2 content of the air plays no significant role.

3.6. DISSOLVED OXYGEN (DO)

Dissolved Oxygen (DO) is another major environmental parameter in soilless plant systems, promotes root growth of plants, and increases nutrient uptake. Oxygenation systems (e.g. air stones/air pump systems) provide for oxygen, especially in NFT and DWC. The lack of oxygen may lead to reduction in plant defence mechanisms against plant pathogens. According to Henry's law, the solubility of air oxygen mainly depends on water temperature and the partial pressure of oxygen in the air. The lettuce growth slows down under low temperature conditions and applying highly concentrated dissolved oxygen to the nutrient solution reverses this situation. Highly concentrated dissolved oxygen (20-30 mg/l) can also be supplied to improve the lettuce growth under 12°C in a deep hydroponic culture [42]. Lettuce will grow satisfactorily at a DO level of at least 4 ppm. If no oxygen is added to the pond, DO levels will drop to nearly 0 ppm. The absence of oxygen in the nutrient solution will stop the process of respiration and seriously damage and, eventually, kill the plant [21]. Additionally, low levels of DO can result in the growth of anaerobic pathogens and acceleration of anaerobic processes, such as Denitrification [43].
DO is one of the most important factors affecting the growth and survival of Nile Tilapia. The optimum DO is in the range of 5-9 ppm. Low dissolved oxygen levels are directly or indirectly responsible for more fish deaths than all other factors combined. Fish, like humans, need oxygen to breathe. The amount of oxygen absorbed by a fish is determined by its size, feeding rate, level of activity, and temperature [34].

3.7. PH

The pH value is kept between 5.0–6.5 in hydroponic systems [23] and 6.0–9.0 in aquaponic system experiments [8], respectively. Levels of pH in systems should be measured daily. Acid and alkaline solutions can be used to regulate pH level in Hydroponics. pH levels in aquaponic systems may decrease over time. The nitrification process of converting fish waste into plant available nutrients has an acidifying effect on the water within the system, hence, it can lead to low pH.

Using an additive helps stabilise the pH and provides a better long-term solution. Shell grit is a popular and readily available additive that will work to raise and stabilize the pH level of the tank. Using a growing media that is slightly alkaline can also prove useful. The pH can also be adjusted by adding HCl (acid) and Na_2CO_3 (base) in aquaponic systems [44]. When the pH level of the hydroponic system is high, to reduce pH level, certain acids are recommended, such as nitric, muriatic, and phosphoric. Our opinion is to use nitric acid (HNO_3) because it is the safest of the three acids (it is an ingredient in cola drinks, for instance) and it adds some phosphate into system, which plants will like as it serves as a fertiliser. When the pH level is low, it can be adjusted by adding potassium hydroxide (KOH).
The optimum pH for Tilapia is within the range of 6.5 to 9. The pH can significantly affect or stump the growth rates of Tilapia, as well as, affect its FCR. A pH of 6 has been found to significantly affect tilapia growth performance ($p \leq 0.05$) [45,46]. Controlling the pH level in an aquaponic system is a meticulous process that requires the calculation of all related parameters, as well as, constant monitoring of the system since the optimum common range between plants and fish is relatively limited (6.5-7) and the pH is always naturally dropping due to constant nitrification of the water solution. Increasing the buffering capacity of the system by increasing water hardness can be useful to better regulate this fluctuation.

3.8. ELECTRICAL CONDUCTIVITY (EC)

In Hydroponics and Aquaponics, measuring the electrical conductivity of the water allows an estimation of the nutrient concentration. So, whilst the pH level is a good indicator for the balance of available nutrients, EC gives an idea of the quantity available. The EC value gives a more detailed insight into the actual processes in the nutrient supply than the sole measurement of the pH value. The EC value is maintained between 1.5 and 2.0 dS/m in Hydroponics and between 0.7 and 0.8 dS/m in the aquaponic system, respectively [24]. Benoit and Ceustermans, (1987) [47] and (1988) [48], measured an electrical conductivity (EC) of 2.2 for the Hoagland solution and recommended in their studies for Hydroponics to keep the EC range between (2.0-2.5 dS/m). Therefore, this EC range is used in (1.5- 2.5 dS/m) in hydroponic cultivations of the AWESOME experiments. Over time EC will change depending on the quantity of nutrients available in the system, and thus, should be measured regularly.

- If the EC measurement stays the same, it shows that the plant is using as much water as it is using nutrients and is balanced. In this case, the nutrient tank should be topped up with a solution of identical concentration to maintain the balance, but it is still necessary to check regularly that the system remains balanced.
- If the EC measurement shows decreasing values, it indicates that the plant is using up more nutrients than water. Nutrient solution of a concentration that restores the solution to its original EC value should be added. Additionally, it can be tested whether a balance can be achieved by a higher nutrient concentration (leading to a higher EC value as well). Doing this, the EC value and the plants' reaction should be monitored carefully.
- If the EC measurement goes up, plants are using more water than nutrients, and more water (without nutrients) should be added, in order to dilute the solution. Burned leaf tips and

slowed growth can be signs of overfeeding and if so, the nutrient solution may be too strong. Temperatures can also affect this, and on hotter days the plants may take up more water without being over fertilised.

In aquaculture, the EC is a less relevant, as it is a cumulative parameter. However, concentrations of single substances, e.g., ammonia, are much more important for aquaculture, since high concentrations may have toxic to lethal effects on fish.

3.9. FERTILIZATION

3.9.1. Fertilization in Hydroponics

A fertilization program is applied to plants by formulating nutrient solutions as follows. The nutrient solution in the hydroponic systems is adjusted according to the needs of the corresponding plant in the beginning. Nutrient solution is only added, if the EC falls, as described in chapter 3.8.

The essential elements are absorbed by the plant roots as inorganic ions. These elements are characterized as macro and micro elements depending on the requirements of the respective plants. Generally, if an element is required to be less concentrated than 100 ppm in the nutrient solution it is classified as a micro element and if it is required in a concentration higher than 100 ppm it is a macro element. Besides absorbing carbon, oxygen, and hydrogen from the atmosphere and water all the other elements are absorbed as ions of their respective elements: nitrogen as NH_4^+ and NO_3^-, phosphorus as HPO_4^{2-} and $H_2PO_4^-$, potassium as K^+, calcium as Ca^{2+}, magnesium as Mg^{2+}, sulphur as SO_4^-, boron as H_3BO_3 and BO_3^-, copper as Cu^{2+}, iron as Fe^{2+}, Fe^{3+}, manganese as Mn^{2+}, zinc as Zn^{2+}, molybdenum as MoO_4^-, chlorine as Cl^-, cobalt as Co^{2+} and nickel as Ni^{2+} ions. The common nutrient solution used for hydroponic culture is the Hoagland solution. The Table 10 shows the recommended compounds and their amount for the nutrient solutions enabling optimal lettuce growth [49].

Table 10 – The recommended compounds of the complete nutrient solutions for the lettuce in hydroponic systems [49].

Nr.	Compound	concentration of stock solution	Nutrient	Nutrient form	Amount of component [ppm]
1	$Ca(NO_3)_2.4H_2O$	236.16	Ca	macronutrient	160
2	$NH_4.H_2PO_4$	115.08	P	macronutrient	31
3	$MgSO_4.7H_2O$	246.49	Mg	macronutrient	34
4			S	macronutrient	64
5	KNO_3	101.10	K	macronutrient	234
6			N	macronutrient	210
7	$ZnSO4.7H_2O$	0.288	Zn	micronutrient	0.05
8	NaFeDTPA	30.0	Fe	micronutrient	2.5
9	$H_2MoO_4.H_2O$	0.040	Mo	micronutrient	0.01
10	H_3BO_3	0.773	B	micronutrient	0.5
11	$CuSO4.5H_2O$	0.062	Cu	micronutrient	0.02
12	$MnSO4.H_2O$	0.169	Mn	micronutrient	0.5
13	KCl	1.864	Cl	micronutrient	1.77

The fertilization is programmed according to Liebig´s law of the minimum. Liebig's barrel is the barrel with staves of different height. The shortest stave represents the limiting factor (Figure 9). Plants need many different nutrients, so-called essential nutritious elements, to grow healthily. If only one of these elements is deficient, plant growth will be inhibited, even if all the other essential nutrients are available in abundance. This is also true for all other resources such as light and temperatures for the respective plant species. The scarcest resource always restricts plant growth and therefore is referred to as the limiting factor [50].

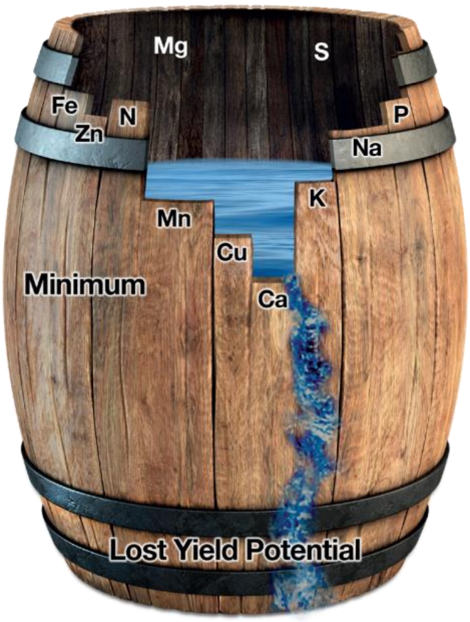

Figure 9 – The Liebig's barrel is the barrel with staves of different height. The shortest stave represents the limiting factor of plant growth [51].

Several researchers reported an enhanced nitrogen uptake when the nutrient solution's nitrogen source contained between 5% and 25% ammonium. At a pH of 6.8, both nitrogen and ammonium are equally absorbed, whereas nitrogen is preferred in acidic and ammonia in alkaline environments. The influence of pH on nutrient uptake is also observed for other macro- and micronutrients. Indeed, a pH from 6.0 to 8.0 is optimal for the uptake of macronutrients such as phosphorus, potassium, sulphur, Ca, and Mg. Considering that micronutrients such as iron, manganese, boron, copper, and zinc are preferentially absorbed at pH values below 6; the trade-off pH in Hydroponics is approximately 5.5–6.0 [8,22].

If the pH of the nutrition solution is too high, nitric acid (HNO_3) is added to the solution whereas if the pH is low, Potassium hydroxide (KOH) is added for adjustment. If symptoms of plant element deficiency are observed, the cause of the deficiency should be identified and the missing plant nutrient be added to the nutrient solution tank.

3.9.2. Fertilization of seedlings for Hydroponics

Before beginning experiments or the actual cultivation in a hydro- or aquaponic system, lettuce seedlings have to be grown. In the lab scale experiments of AWESOME, 450 lettuce seeds are sown with 1-2 cm depth into trays (209 seedlings can be grown in a tray, the size of trays 70 X 40 cm) with the media type selected according to the results of a seedling experiment conducted as a pre-test. Seedlings raised in a mixture of 70% peat moss + 15% vermiculite + 15% perlite developed satisfactory, hence, this mixture was chosen as the designated media-type for seedling cultivation. As a part of the media preparation, 8.5 g of N-P-K, 19.19.19 + T.E (19% Nitrogen, 19% Phosphorus, 19% Potassium (macro elements) + trace elements (micro elements such as molybdenum, boron etc.)) fertilizer is added to the growing media for one complete seedling tray (209 cells) and is added during the cultivation periods together with the irrigation. After sowing, the seeds are planted and they remain covered in a warm environment (in incubation) for 1 day in summer, while for 2 days in winter. After this time has passed, they are taken to a bright place in the greenhouse and sprayed with 1 l of water twice a day. Once the cotyledons are fully expanded and the first true leaves begin to emerge, the seedlings are sprayed once every 3 days with a dose 0.5 g of (N-P-K (19/19/19) +TE) balanced fertilizer (because N, P, K rates are equal in the fertilizer) per 1 L of water. This solution should have an EC in the range of 1.5 -2.0 mS/cm and pH in the range of 5.4–6.0. During summer, irrigation might be needed twice a day, once with water only and once with the nutrients, respectively around 6-7 a.m. and 5-7 p.m. In the winter time, irrigation once a day is sufficient. The fertilization programme for the seeds/seedling propagation is summarized in Table 11.

Table 11 – Fertilization programme for seedling propagation.

Fertilization time	Implementation and its descriptions
Media preparation	0.5 g of (N-P-K, 19.19.19 + T.E) fertilizer is added into growing media for 1 complete seedling tray (209 cells) together with the irrigation water
Incubation	After sowing seeds, seedling trays are kept in a warm environment for 1 day (summer) or 2 days (winter). During this period, the trays are not irrigated or fertilized as they are covered. Later, they are taken to a place for seedlings in the greenhouse.
After incubation to transplanting time of seedlings	- In summer time, irrigation with water or nutrition solution will be conducted twice a day (around 6-7 am and 5-7 pm). - In winter time, irrigation with water or nutrition solution will be conducted once a day. - Once the cotyledons are fully expanded and the first true leaves begin to emerge, the seedlings are sprayed once every 3 days with a dose 0.5 g of (N-P-K (19/19/19) +TE) per 1 l of water. This solution should have an EC in the range of 1.5 -2.0 and pH in the range of 5.4–6. - The last 3 days before transplanting the seedlings to the hydroponic systems, lettuce has to be watered without fertilizer. 23±2- day after, the old seedlings are transplanted.

3.10. AMMONIA LEVELS

Plants rely on several different nutrients in the water for proper growth, when cultivated in a hydroponic system. Too high nutrient concentrations can have a negative effect on plant development, but this is not comparable to the toxic effect that specific substances can have on fish. While ammonia is a fertilizer to plants, it is highly toxic to aquatic organisms.

All aquatic animals are very sensitive to ammonia levels. As waste, fish excrete ammonia and smaller amounts of urea into the water. In aquaculture systems, there are two types of ammonia: ionized and non-ionized. Ammonia in its un-ionized form (NH_3) is extremely dangerous, although ammonia in its ionized form (NH_4^+) is not as dangerous as NH_3 but in certain concentrations, it also becomes toxic. Total Ammonia Nitrogen (TAN) refers to the nitrogen in both types of ammonia. Toxic ammonia can be converted to unharmful nitrates by biological mechanisms, which happen in the biofilter of Aquaponics systems.

Because of the low stocking densities of fish in natural environments such as lakes, ammonia levels never reach dangerously high concentrations. However, the fish farmer must maintain high densities of fish and so faces the risk of ammonia toxicity [34].

Non-fish-toxic levels of Ammonium-Nitrogen (NH_4-N) are under 0.5 ppm. However, for Ammonia-Nitrogen (NH_3-N) it is usually less, and generally required to be maintained below 0.0125 ppm [52]. Overall, the increased levels of ammonia in the water can result in mucus secretion and haemorrhage in the gills, and can become lethal as increases. However, Tilapia fish have been shown to be significantly more resilient to such contaminants, and such resilience even improves as the fish grows [52].

3.11. PESTS, DISEASES AND CONTROL STRATEGIES

A major advantage of hydroponic and aquaponic systems is that soil-borne pests and diseases are hindered by the lack of soil. Hence, this single factor limits the occurrence of pests and diseases. A challenging by-product, however, is that the crops are grown in a confined space, in a closed system, and with high density. As a result, when diseases and pests appear, they can spread easily from one plant to another. It is a similar problem with water borne diseases as they can easily spread through the water, too[53]. On lettuce, the main pests that can be observed are aphids, thrips, whiteflies and other. On the other hand, crop yield can be greatly increased by using chemical control methods, but the misuse (including overuse) of synthetic chemical compounds can result in environmental pollution, toxic or lethal effects on the non-target organisms like fish in aquaponic setups, and consequently negative effects on human health. Moreover, the repeated and frequent use of insecticides and acaricides can lead to resistance development in pests like spider mites [51,52].

To reduce environmental contamination and negative effect on human health by using pesticides, integrated pest and disease management strategies are used to combat plant pathogens and pests. Integrated disease and pest management (IPDM) is an ecologically based pest and disease control strategy that relies on mostly natural mortality factors such as natural enemies and weather, and searches for control tactics that minimize negative environmental effects and negative effects on human health, and replaces excessive use of pesticides with other control methods. IPM also has pesticides at its control list, but only after systematic monitoring of pest populations and spreading of disease. Chemical control may seem the easiest and cheapest method to apply, but the use of pesticides should be the last option in IPDM due to their detrimental effects on non-target organisms. Consequently, the use of pesticides among other control methods such as cultural, physical, biotechnical control methods should be the last solution for combating pests and diseases on the lettuce [54].

Pest and disease monitoring are of great importance in order to nip emerging incidents in the bud. Thus, in addition to careful observation of the plants, it is also advisable to use sticky traps for pest detection. These traps are blue or yellow cards, some of which also contain pheromones to attract the pests [22].

More than 75 diseases have been reported on lettuce plants and are caused by viruses, fungi, bacteria, nematodes and oomycetes [55]. Table 12 summarizes the most common diseases in lettuce grown in hydroponic and aquaponic systems.

Table 12 – List of common diseases of lettuce grown with Hydroponics or Aquaponics

Disease	Causal agent	Microbial type	References
Grey mold	*Botrytis cinnerea*	fungus	[56,57]
Powdery mildew	*Golvinomyces cichracearunm*	fungus	[21,58]
Fusarium wilt	*Fusarium oxysporum f.sp. lactuca (FOL*	fungus	[59]
Lettuce drop	*Sclerotinia spp*	fungus	[60]
Phytium root rot	*Phytium spp.*	oomycete	[61]
Phytophthora root rot	*Phytophthora spp.*	oomycete	[62,63]
Downy mildew	*Bremia lactucae*	oomycete	[64,65]
Bacterial wilt	*Ralstonia solanacearum*	bacteria	[66]

Lettuce can be attacked by aphids, white flies, spider mites, thrips, fungus gnats, cutworms, leafminers, cabbage loopers, slugs, and snails. Many pests can be observed in lettuces grown in Hydroponics in hot and dry climates such as Egypt's. An advantage of these soilless systems, pests are not able to hibernate in soil and plant remains. Table 13 summarizes the most common pests in lettuce.

Table 13 – The most common pests in lettuce grown in Hydro- and Aquaponic systems [22].

Pests	Latin name
Thrips, particularly Western flower thrips (WFT)	*Frankliniella occidentalis*
Rutherglen bug	*Nysius vinitor*
Currant lettuce aphid (CLA)	*Nasonovia ribisnigri*
White fly	*Besimia tabaci*
Spider mite	*Tetranychus urticae*
Thrips	*Frankiniiella occidentalis* or Thrips *tabaci*

IPDM involves various combinations of control methods of preventative, biotechnological, cultural, physical, mechanical, biological and chemical control. The steps using the IPM approach are listed in Table 14. Generally, the IPDM approach is followed in the experiments conducted as part of the AWESOME project.

Table 14 – Chronological procedure when using the IPDM approach

IPM Steps	Pest and disease management procedure
Prevention	Sanitation of work equipment and soilless systems, pest and disease detection and identification, monitoring of pest or disease, reviewing and selection of control methods
Cultural control	Selection of disease resistant crop variety, environmental manipulation such as lowering humidity, planting certified seeds, disinfecting tools, using pathogen- free water
Physical control	Jet streaming with water (for pests), Ultraviolet irradiation (for water-borne pathogens), Blue-light emitting diodes, heating
Mechanical control	Picking/blasting
Biotechnical control	Sticky cards, phenomena traps
Biological control	Predators, parasitoids (special type of parasitism), microbial inoculant, entomopathogenic fungi
Chemical control	Insecticides, fungicides, pesticides can lead to destruction of beneficial bacteria, alteration of biofilter efficiency, residual effect on fishes in aquaponic systems

In Aquaponics, chemical control can have a negative effect on fish, this applies in particular to insecticides of the group of organochlorine, organophosphorus and carbamate compounds which have similar characteristics [67].
Table 15 offers an overview of common pests and diseases appearing when cultivating lettuce in Hydroponics greenhouses and their control mechanisms.

Table 15 – Common pests and diseases when cultivating lettuce in hydroponic greenhouses and the corresponding control mechanisms.

Pest or disease	Combat mechanisms	Combat type	Restrictions
Gray mold fungus (*Botrytis cinerea*)	Fenhxamid	Fungicide (CPC)	Residue on plant
	Captan	Fungicide (CPC)	Residue on plant
	Bacillus megatierum	Biocide	
	Chloride (cultural control)	Chloride (cultural control)	
Thrips *(Frankliniiella occidentalis* or Thrips tabaci)	*Orius aldipennis*	Predator (BPC)	
	Orius laevigatus	Predator (BPC)	
White fly	*Amblyseius swirskii*	Predator (BPC), e.g. combats juvenile stages and egg, etc.	These predators do not work over 35°C
	Beauveria bassiana	Entomopathogenic fungi	
	Lady beetles *Delphastus catalinae*	Predator (BPC), feed voraciously on whitefly eggs and nymphs, often not appropriate for poinsettias due to high egg and nymph demand	
Spider mite (*Tetranychus urticae*)	*Amblyseius swirskii*	Predator mite (BPC)	

Pest or disease	Combat mechanisms	Combat type	Restrictions
	Phytoseiulus persimilis	Predator mite (BPC)	These predators do not work over 35°C.
Currant-lettuce aphid (*Nasonovia ribisnigri*)	*Aphelinus abdominalis*	Parasitoid (BPC)	
	Pirimor® 2 Day WHP, Movento® 2 sprays per crop, 3-day WHP	CPC	Pesticide residue on plant

CPC: chemical pest control, BPC: biological pest control, WHP: Withholding periods (WHP) after pesticide application

3.12. AQUACULTURE DISEASES AND TOXINS

3.12.1. New tank syndrome

Aquarium hobbyists use the term "New Tank Syndrome" to describe fish that are poisoned by high levels of ammonia (NH_3). This phenomenon also occurs when starting up new ponds. Ammonia is produced by the bacterial mineralization of fish waste, excess food, and the decomposition of animal and plant tissues. Additional ammonia is excreted directly into the water by the fish themselves. Ammonia poisoning causes damaged tissue, especially to the gills and kidney. It also causes physiological imbalances such as impaired growth, decreased resistance to disease and death. High levels of nitrite are also a problem. Nitrite poisoning inhibits the uptake of oxygen by red blood cells. Known as "Brown Blood Disease," or Methaemoglobinemia, the haemoglobin in red blood cells is converted to methaemoglobin [68].

3.12.2. Fish diseases

Diseases are an unavoidable result of intensive fish farming systems. Bacterial, viral, and parasitic disease outbreaks have a major negative effect on Tilapia farms around the world. Listed in Table 16 are some of the most common diseases that infect fish, specially tilapia, and their causing agent.

Table 16 – Most common diseases in aquaculture.

Disease	Causal agent	Microbial type	References
Enteric redmouth disease (ERM)	*Yersinia ruckeri*	Bacteria	[69]
Monogenic	*monogenetic trematodes*	Parasitic flatworms	[70]
Trichodina	*Trichodina, or "Trich"*	Protozoan parasite	[70]
Columnaris, Gil and Tail necrosis	*Flavobacterium columnare*	Bacteria	[71]
Streptococcosis	*genus Streptococcus.*	Bacteria	[72]
Aeromonas infection	*Aeromonas hydrophila*	Bacteria	[73]
Viral Hemorrhagi septicemia	*Novirhabdovirus*	Virus	[71]
Viral nervous necrosis (VNN)	*Betanodavirus*	Virus	[70]
Dermal mycosis/ Saprolegniasis	*Saprolegnia*	Virus	[70]

3.13. FEEDING

Feeding rates and protein content differ according to different fish weights. Changing and adjusting the fodder quantity and type plays a great role in optimum growth of fish in rearing tanks. The following table is describing the different feeding rates in each stage/ weight of cultivated fish.
To get the desired efficiency of the fodder, the fodder used should be of a good quality, properly stored, and free of any lumps and fungal infections. Daily feeding amount of tilapia fish should be calculated according to their weight and age, the Table 17 below describes the related calculations.

Table 17 – Fish feeding rates according to fish weights.

Fish weight (A)	Total fish weight/ tank (B)	Feeding rate (kg fodder/ kg biomass/ day)	Fodder/ kg
1- 50 g	Fish weight (A) multiplied by the number of fish in each tank	5%	=B · 5/ 100
50- 100 g		4%	=B · 4/ 100
100- 200 g		3%	=B · 3/ 100
200- 400 g		1.5- 2%	=B · (1.5-2)/ 100

1. Divide the meals three times; the first one to be from 7 a.m. in summer and 8 a.m. in Winter, second meal at 12 a.m. in Summer and 1 p.m. in the winter and the last one at 5 p.m. in Summer and 4 p.m. in Winter to get the best conversion rate.[74]
2. Distribute the feed throughout the tank.
3. Observe the fish and watch their appetite for the fodder.
4. Avoid feeding fish in the following cases:
    a. When any signs of illness appear or when any abnormal movement of fish is noticed
    b. When the air and water temperature rise more than 30°C - In this case reduce the feeding rate to 1% and when the water temperature drops below 19°C
5. Remove the remaining feed, which is floating at the surface, from the water 25 minutes after each meal by hand
6. Use Vitamin C before the Winter season; to raise the immunity of fish in the months of 9 and 10 from 5-7 days each month at a dose of 5 g/kg feed. Also, in Summer do the same to resist heat stress on fish with the same dose of 5-7 days for each of the months 6 and 7.

4. CONCLUSION

Hydro- and Aquaponics are highly technological methods for plant cultivation and fish or shrimp farming. The plants and fish species are grown in closed-loop and soilless systems, which greatly reduce the dependence on the surrounding natural conditions. Hence, environmental conditions for optimal plant and fish or shrimp growth can be provided. However, this also means that the influencing parameters that affect the performance of the plants and fish must be known and are adjusted accordingly on the system side. In Aquaponics, a particular challenge is to carefully coordinate aquaculture and Hydroponics components to make the best use of synergies. On the side of Hydroponics, the essential parameters are light, temperature, fertilizer use, water quality, and also pest and disease management. In Aquaponics, the demands of the fish or shrimp need to be considered as well as the interaction of aqua- and hydroculture. Bacterial metabolic processes are required to make waste products from aquaculture available to plants. Therefore, mechanical and biological filters have to be added in an aquaponic system. For the plant and fish unit themselves, water circulation and exchange have to be regulated as well as quality parameters like ammonia, pH, or dissolved oxygen. Feeding rates have to be calculated, and it is beneficial to analyse the wastewater composition to determine if additional nutrition for healthy plant development is needed.

Obviously, these techniques require high capital investments and good knowledge about the influencing factors and their relationship as well as technical know-how about the operating system. These requirements make it hard to get started on a commercial scale. Nevertheless, the potential of Hydro- and Aquaponics to contribute to a resilient food supply in the future is considered high. The reasons for this evaluation are the much higher yield densities and shorter cropping cycles compared to traditional agriculture. In addition, massive water savings and independence from prevailing soil conditions make the technology even more attractive, especially for farmers in hot arid climate zones.

In this first Deliverable of WP5, the technical requirements needed of Hydroponics and an Aquaponics system as well as the influencing parameters have been described. Particular focus was placed on the ideal conditions for growing lettuce and Nile tilapia, as these species are being studied within the AWESOME test facilities. Currently, the Hydroponics and Aquaponics setups presented in this report are tested within the AWESOME lab scale facility. Aim of the experiments in this facility is to determine the hydroponic subsystems and configurations, which are suited best for lettuce cultivation in Hydroponics, and lettuce and tilapia production in Aquaponics. For decision-making, biological and economic factors are considered, as well as risks. The best performing systems will be tested in a pilot scale to mimic a commercially operated facility. In the second Deliverable of WP5, the experimental procedures of both facilities will be described and the results analysed. Special attention will be paid to food productivity per unit water in terms of quantity and quality.

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