Cost-benefit analysis into integrated aquaponics systems

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Abstract

Aquaponics represent a sustainable food production technology. There are various policies at the European Union level, notably the Common Agriculture Policy, the Common Fisheries Policy, Food Safety and Nutrition Policy and the Environmental Policy which can provide support for this sector. But, at the same time, it is interesting to see how aquaponics can contribute to the implementation of European policies and, particularly, to an increase in the competitiveness and sustainability. With an ever increasing global population it is becoming ever more difficult to produce food in a sustainable way, while at the same time ensuring high standards for food safety and quality, and also keeping up with the market demand. Aquaponics, the combination of an aquaculture production system (usually a RAS) and a hydroponic system, can be a solution to this issue. In order to carry out an efficient aquaculture, it is necessary to increasingly regard sustainability, consumer requirements, food safety and economic efficiency, through continuously developing new technologies. The aim of this study was to examine the cost effectiveness of six aquaponics systems, where two different aquaponics techniques (nutrient film technique and media grow bed) were applied. For each experimental systems, the cost effectiveness analysis included implementation costs, fixed and variable costs, crop income and a series of economic indicators. Also, a prototype for a technological aquaponics knowledge hub was included. It was concluded that under the experimented parameters, only oregano and red rubin basil are economically feasible to be grown in an aquaponics system, while thyme and parsley failed to turn a profit. The media grow bed aquaponics technique yielded the highest net profit and return, and the same can be said about 31 plants/m^2 crop density. Furthermore, in order to improve the profitability of such systems and to lower costs (especially electricity costs), a more efficient lighting solution and an alternative power source (such as solar panels) must be implemented.

Keywords: Aquaponics. Competitiveness. European policy.

1. Introduction

Aquaponics is the combination of aquaculture (fish growing) and hydroponics (crop of plants without soil), namely mixed growth of fish and plants in an integrated system. Fish waste is an organic source for plants, and plants naturally filter water for fish.

The third participating part is represented by microbes (nitrifying bacteria). These bacteria convert ammonia from fish waste into nitrites, and then into nitrates. Nitrates are the compounds that plants can assimilate and use to grow. Solid waste from fish is transformed into vermicompost, which is also food for plants.

In the context of an increasing global population in the past decades, and subsequently an accelerated increase in food demand, new challenges must be faced, such as: finding sustainable ways of food production, ensuring the highest standards in food safety, security and quality, and overcoming the market’s economic constraints. Thus, meeting these demands while, at the same time, ensuring economic competitiveness must be the key focus that drives the development strategies of the food production industry. Intensive livestock production systems constitute the basis of modern animal husbandry. Out of all the commercial animal husbandry practices, aquaculture is the only one that is not fully intensive. Besides assuring a part of the global food demand, aquaculture also relieves the pressure exerted by the fisheries and their environmental impact.

The Common Fisheries Policy (CFP) and the Common Agriculture Policy (CAP) are both relevant for aquaponics, especially for the aquaculture and hydroponics components. One of the main objective of CFP and CAP is to increase competitiveness and sustainability of agriculture and aquaculture (Massot 2017). Another important European objective is concerning the management of competitive advantage by obtaining high quality, health and environmental standards. (Hoevenaars 2018)

Aquaponics can contribute to reaching the European objectives through a decrease in the impact of waste water and lessening the amount of waste resulting from fishing activities and aquaculture. From an economic point of view, investment in aquaponics is low, the systems being able to be applied both at micro (natural persons) level and at macro (firms) level. The above-mentioned policies also promote productivity growth by using innovative technologies, and aquaponics systems are considered innovative technologies.

Nowadays, aquaculture can be characterized depending on its rearing intensity level as: extensive, semi-intensive, intensive, and very intensive. Recirculating aquaculture systems (RAS) are the only ones that can be characterized as intensive/very intensive aquaculture production systems. This level of intensity also comes with other advantages, such as: very low environmental impact, improved food safety, security and quality, high water conservation, efficient use of space, versatile placement and the ability to assure a continuous production all year round. However, high investment costs discourage potential financiers or aquaculture farmers to implement these systems. Also, a RAS can serve as an excellent breeding and rearing environment for endangered species, therefore, facilitating restocking programs and conservation efforts.

In certain areas of the world, as well as in some countries, RAS prove to be less effective mainly due to energy efficiency issues. Therefore, the profitability of these RAS is starting to be debated. Kurtoglu (2010) emphasizes that RAS will steadily become more important for the sustainability of marine habitats, mostly because of the degradation of land quality and environmental issues, even if this type of systems requires high initial investments costs.

Blidariu and Grozea (2011) promotes aquaponics as a sustainable aquaculture approach due to its similarities with natural systems, using water in an efficient manner and having a limited environmental impact. Aquaponic systems were presented from different perspectives like in Goodman (2011), where he describes it as for personal use, hobby, medium or large scale economic systems, Wardlow (2002) as teaching tools for science education or Metcalf and Widener (2011) as means of increasing food production in urban locations with limited conventional aquaculture production.

According to their financial status, the RAS owners can be divided into two main categories: profitable and not profitable (Fig.1). In the case of the profitable RAS owners, there are two means of maximizing profitability: upscaling the RAS production or integrating an aquaponics system. For production upscaling, RAS owners usually possess the necessary knowledge, but in the case of integrating an aquaponics system, there is a good chance they lack the necessary “know how” (Fig.1). Therefore, there is a need for either self-research or to seek assistance from a third party. On the other hand, a not profitable state can be a consequence of certain issues, such as: market demand, technological expertise, technical system design and other problems (Fig.1). For the first three specific issues, optimal solutions have been proposed for each of them, which could lead to a profitable status of the RAS (Fig.1). However, if none of the issues could be resolved through the proposed solutions, integrating an aquaponics system was suggested as a possible alternative solution, bringing the focus back on the much needed “know how” (fig.1).

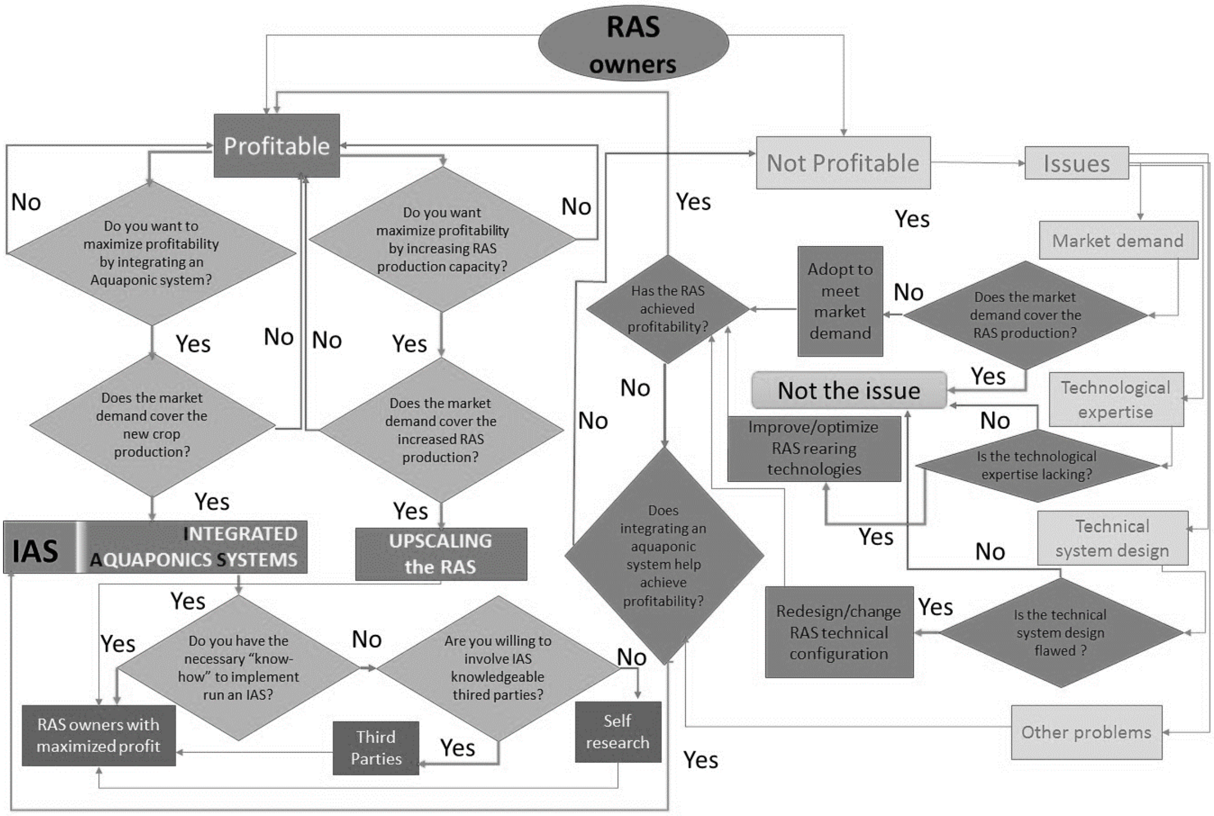


Fig. 1. RAS improvement logical diagram (original diagram)

2. Literature Review and Motivation

Several articles regarding the economic potential of aquaponics systems were made. In his small scale aquaponics research, Chiang (2009) stated that it is very cost-effective to grow vegetables and to rear fish (barramundi and rainbow trout), also providing numerous benefits, especially with worldwide challenges regarding food shortages and climate change. Furthermore, he recommends scaling up the production of aquaponics systems to more cost-effectively serve local food demand (Chiang, 2009).

Red amaranth productivity and water quality were subject of a study performed by Medina et al. (2016) which involved two aquaponics systems where blue tilapia was used. He correlated his results also with an economic study of the systems. As main finding of his study, we could notice that he managed to show that increasing plant productivity in a low protein context, could increase the overall revenue even if the fish production will decrease.

Petrea et al. (2016) made a cost-effectiveness analysis between several aquaponics technologies using different fish-plant combinations, such as rainbow trout – spinach, stellate sturgeon – spinach, stellate sturgeon – basil, stellate sturgeon – mint, and stellate sturgeon – tarragon. He concluded that growing spinach while rearing stellate sturgeon was the most feasible.

Another analysis, involving lettuce and pak-choi was reported by Hambrey Consulting, in 2013, for the New Zealand Aid Programme. In their presented analysis, they managed to prove that in the context of large aquaponics systems, growing these plants could be profitable. Therefore the study suggest that aquaponics have a real advantage over stand-alone aquaculture production system as a mean of generating high quality food in particular locations, such as soil deficient islands (Hambrey Consulting, 2013).

In their survey Love et al. (2015) concluded that aquaponics is a growing form of aquaculture that easily fits into a local and regional food system model in part because it can be practiced in or near large population centers. Also, they found that gross sales revenue and profitability were higher for operations that diversify their revenue stream by selling non-food products, services, or educational trainings (Love et al., 2015).

Even if aquaponics research intensified only during the past years, there are also older studies on the profitability of aquaponics farms. For example Bailey et al. (1997) concluded that aquaponics farms can be profitable; through his research based on farms growing lettuce by using tilapia as ‘fish layer’ he demonstrated that total revenues managed to exceed the total cost of production. Still, even if all farms were on the positive side in term of returns, it was clear that smallest farm involved higher risks associated with aquaponics systems and a safer approach can be found in the context of larger farms.

Getting closer to 2017, we can notice Engle (2016) study on the profitability for different crop types like tomatoes, lettuce or basil. In his research he showed that these three plants can be profitable, especially basil, due to higher prices that are charged for fresh condiments. Still, in his research, Engle (2016) identified also a downside and that is the fish part of the aquaponics systems. So, the fish component proved to be not profitable, tilapia productions costs exceeding market price just in one case. In Engle opinion, the fish component of an aquaponics system represents the weak part, with profitability coming mainly from the vegetable portion. Engle (2016) emphasize that fixed costs can increase due to special investments in special equipment (for packaging or chilling) when expansion of the system is required. Low profitability of the fish component in aquaponics systems is described also in other studies, like Bailey et al. (1997) or Holliman et al. (2008). They also emphasized that fish side can be weak on profitability, but plants like basil and lettuce can be very profitable in the context of aquaponics systems. For aquaponics owners it is important to gain access to premium prices markets. In studies like Engle (2016) this is almost a mandatory condition for the vegetables and fish production to bring profit. In order to maximize profit, the business strategy should include a careful analysis of the additional costs and risks that are associated with these engineering complex systems, before doing actual investments.

There are also studies that emphasize also the fish potential in aquaponics. For example, Tokunaga (2013) observed also that plants and vegetables have a higher market value, being the responsible factor for the economic outcome, but also that there is a good potential in increasing fish profitability by increasing the volume of production. Besides this, Tokunaga (2013) puts a lot of accent also on the consumer behavior in respect to aquaponics products. For him, the consumer behavior is important due to the fact the economic outcome is tightly related to product prices, and it is important to properly understand for what type of customers we are aiming for.

Love et al (2014), in his research, presents a different approach, energy related, that could help in maximizing profit. He believes that by using renewable energy sources in aquaponics system would reduce associated energy costs.

Rupasinghe (2010) investigates and compares the financial outcomes for an aquaponics system consisting in lettuce and barramundi fish versus growing the plants and fish in separate systems. He concludes that by integrating together the hydroponic system with the aquaculture one, clear benefits were obtained, mainly due to the reduction of fertilizer costs. Same ideas were previously stated by Adler (2010) that emphasized the positive effects of putting together aquaculture and plant production system through cost reductions coming from combining management, nutrients, water and capital costs like transportation or equipment's.

Chaves et al. (1999) research was targeted to increase the profitability of recirculating system for catfish production by including a vegetable component represented by a tomato production layer. Chaves (1999) concluded that, from an economic point of view, is feasible to put together fish and crop production in the case there are high margins from both production components.

Linky et al. (2005) stated that the financial prospects of an aquaponics system may reduce costs by using as input a waste stream coming from another industrial activity.

Xie and Rosentrater (2015) studied aquaponics field both from profitability and environmental perspectives. Their research, which involved basil growing, demonstrated that system scale and plant price clearly influenced the profit. Therefore, the aquaponics business was profitable only when the scale was large enough. From Xie (2015) economic analysis, a good business strategy was to sell the herbs at a relative high price. English (2009) concluded that it is likely that a combination of direct and wholesale methods would be necessary in order to properly capture market demand and maximize farm profits. She advises to investigate alternative species, such as catfish or bluegill, for aquaculture production or to move away from aquaculture sales and focus solely on the hydroponic aspect of the system (English, 2009).

On profitability, Tokunaga et al. (2015) emphasized that in the case of the large aquaponics systems the profits are not as big as reported in other studies. This situation is raised by the fact that most of the estimates were involving commercial operation and not experimental cases, where real commercial operations are facing challenges like supply chain logistics issues. Tokunaga (2015) considers also that as the industry and technology will mature even more, we will see even a greater increase in the productivity of aquaponics systems. From his perspective, there is real potential for aquaponics systems to supply both vegetables and fish to the market. The purpose of this study is to demonstrate that aquaponics is a viable solution for improving RAS profitability.

Therefore, after reviewing the literature it was concluded that no studies have been made in order to offer a worldwide solution or "know how" support for prospective aquaculture, especially sturgeon aquaculture, and aquaponics farmers that lack the necessary operating knowledge.

3. Materials and Methods

The results presented in this research paper were obtained during six experiments that were conducted within the RAS pilot station at the Department of Aquaculture, Environmental Science and Cadaster of the Food Science and Engineering faculty, “Dunarea de Jos” University of Galati in Romania. All six of the experiments (ON1, ON2, OH1, BN2, TN2 and PN2) were performed by integrating two types of aquaponics systems with an already existing RAS, each of them using a different aquaponic technique. Lighting equipment was also installed to ensure proper plant growth during the experimental periods.

In the conducted researches two type of sturgeon were used (Hybrid sturgeon and Russian sturgeon). The reason behind choosing these two species was justified by the fact that sturgeons are fish species with high economic value, especially for their caviar. This specific trait makes them suitable for being reared in RAS conditions.

The interest in rearing hybrid sturgeon was represented by the desire to achieve sexual maturity at a much faster rate in order to obtain its caviar. On the other hand, Russian sturgeon is a critically endangered species and it was reared for the purpose of restocking the natural habitat as part of the worldwide conservation effort. As to the plant species, four were chosen (Oregano, Red Rubin Basil, Thyme and Parsley).

The criteria of choosing these four plants is the fact that they have a significant economic value, they are much sought herbs for their aromatic and nutritional properties and they have a high market demand worldwide. The reason behind the two applied crop densities lies in the succession order of the six experiments. The first three experiments (ON1, ON2 and OH1) were conducted at the same time, using a density of 62 plants/m^2 (ON1 and OH1), respectively 31 plants/m^2 (ON2).

A higher individual crop average yield was obtained with the lower density due to a much better plant welfare as a result of a larger lateral growing space, see Fig 2 and 3. The Fig. 2 presents Oregano plant in a NFT aquaponics system at the beginning and at the end of the experimental period, while Fig. 3 presents also Oregano in a MGP aquaponics system at the end of the experiment phase.

Fig. 2: Oregano (*Origanum vulgare*) in the NFT aquaponics system – at the beginning of the experimental period, in a 62 plants/m^2 crop density (top) and towards the end of the experimental period, in a 31 plants/m^2 crop density (bottom)

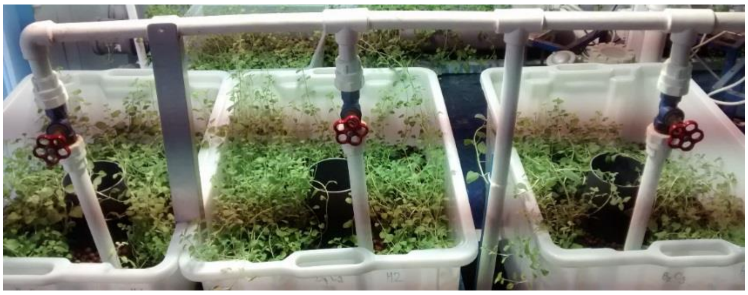


Fig. 3: Oregano (*Origanum vulgare*) in the MGB aquaponics system – towards the end of the experimental period, in a 62 plants/m^2 crop density

The next three experiments (BN2, TN2 and PN2) were also conducted at the same time, this time applying only the lower plant density of 31 plants/m^2, as a direct outcome of the previous experiments registered results. In order to be able to make a long term feasibility analysis for each of the six experimental variants is essential to determine the crop growing technique. Therefore, the staggered technique was applied to generate a constant cash flow. The staggered growing technique consisted in introducing a new crop into the system every seven days after the beginning of the experiment. After 42 days, the first crop is harvested, and every seven days after that another crop can be harvested, this way assuring that not all plants in the system achieve harvest size at the same time, hence the possibility of a constant income.

Because it takes a while to set in motion a staggered production system, the first operating year will yield only 47 cycles. Thus, it takes six weeks to complete a full growth cycle, circumstance that leads to no crop being harvested in the first five weeks of the first operating year. Starting with the second operating year, the system outputs the maximum of 52 growth cycles. Unlike the staggered technique, the batch growing technique utilizes the entire growing area from the beginning of the cultivation period until the (entire) crop is harvested. This means that it takes the same 42 days to grow one crop and the aquaponics system generates income every 42 days. Within a year, and with efficient system population and harvesting, only 8.69 crop cycles can be harvested.

Next section of the paper will present our experiments results and insights over these results. For this, two types of calculations were performed: technical-technological and cost-effectiveness. As such, the following formulas were used:

a. For technical and technological indicators analysis:

$$HLR = \frac{Q}{S} \quad (1)$$

where HLR = hydraulic loading rate (m/day), Q = aquaponics module inlet flow rate (m^3/day) and S = aquaponics module area (m^2).

$$HRT = \frac{S * h * n}{Q} \quad (2)$$

where: HRT = hydraulic retention time (hours), h = water depth within the aquaponics module (m) and n = growing substrate porosity.

$$LAI = \frac{L}{S} \quad (3)$$

where: LAI = leaf area index (m^2/m^2), L = total leaf area (m^2), S = aquaponics module area (m^2),

$$RGR = \frac{1}{\frac{DWi + DWf}{2}} * \frac{DWf - DWi}{t} \quad (4)$$

where, RGR = relative growth rate (g/g/day), DWi = initial dry weight (g), DWf = final dry weight (g) and t = number of days,

$$NAR = \frac{1}{\frac{Li + Lf}{2}} * \frac{DWf - DWi}{t} \quad (5)$$

where NAR = net assimilation rate (g/m^2/day), Li = initial leaf area (m^2) and Lf = final leaf area (m^2),

$$CGR = \frac{1}{S} * \frac{DWf - DWi}{t} \quad (6)$$

where CGR = crop growth rate (g/m^2/day),

$$Avg.LAR = \frac{1}{2} * \left(\frac{Li}{DWi} + \frac{Lf}{DWf}\right) \quad (7)$$

where Avg. LAR = average leaf area ratio (cm^2/g).

b. For the cost-effectiveness analysis:

$$TI = P * Q \tag{8}$$

where TI = total income (production value), P = selling price for 1 kg of plants (€/m^2/production cycle) and Q = production quantity (g/m^2/production cycle).

The selling price (P) was obtained by analyzing market prices for oregano, red rubin basil, thyme and parsley.

$$TPC = TFC + TVC \tag{9}$$

where TPC = total production costs (€/m^2/production cycle), TFC = total fixed costs (€/m^2/production cycle) and TVC = total variable costs (€/m^2/production cycle).

We have considered fixed costs those costs that do not change their value depending on the production volume.

$$Pr = TI - TPC \tag{10}$$

where Pr = profit (€/m^2/production cycle),

$$Re = \frac{Pr}{TPC} \tag{11}$$

where Re = rate of return,

$$RPr = \frac{Pr}{TI} * 100 \tag{12}$$

where RPr = rate of profit (profitability ratio) (%).

4. Results and Discussions

4.1. Technical and technological considerations

The fish feed, and therefore the resulted metabolic byproducts – the nutrients, are the most important input for an aquaponics system. The absorption degree of these nutrients by the vegetable biomass is mostly influenced by the technical characteristics of the system. Two of these characteristics that stand out are the hydraulic loading rate (HLR) and the hydraulic retention time (HRT). Therefore, when designing an IAS the HLR is the key in correlating the ratio between the water flow rate and the growing area. This ensures an optimum nutrient absorption as long as the technological water input is monitored and regulated according to the data obtained from its chemical analysis.

The IAS efficiency and optimal functioning, in terms of vegetable biomass growth, can be easily identified, even from the start of the production cycle, by analyzing the nutrient retention rate, which are directly influenced by the hydraulic retention time. However, the HRT varies when using a batch production technique, fact justified by the different nutrient demand of plants in each of their growing stages. In present experimental designs, the different values of HLR and HRT (Table 1), recorded at the OH1, where MGB technique was applied, comparing with the rest of the experimental variants (ON1, ON2, BN2, TN2, PN2), where NFT techniques was applied, are generated by the constructive design hydraulics constrains corresponded for each of the two applied aquaponics techniques (MGB and NFT). Thus, it can be observed that oregano biomass has the highest requirements in terms of light hours per day, comparing with the rest of plant species (Table 1).

Table 1: Technical data

	ON1	**ON2**	**OH1**	**BN2**	**TN2**	**PN2**
Aquaponics technique	NFT	NFT	MGB	NFT	NFT	NFT
Inlet flow rate (m^3/hour)	0.525	0.525	0.525	0.525	0.525	0.525
HLR (m/day)	98.82	98.82	50.00	98.82	98.82	98.82
HRT (hours)	0.00018	0.00018	0.03168	0.00018	0.00018	0.00018
Luminous flux (lm)	6240	6240	6240	6240	6240	6240
Artificial lighting* (hours/day)	12	12	12	8	8	8

* The luminous flux was measured with a lux meter and the values were averaged.

Also, it must be emphasized that technical data presented in Table 1 influence the technological data, presented in Table 2, which in turn influence productivity and therefore the economic performance.

Table 2: Technological data

	ON1	**ON2**	**OH1**	**BN2**	**TN2**	**PN2**
Fish species	Hybrid sturgeon (*Acipenser ruthenus* x *Huso huso*)			Russian sturgeon (*Acipenser gueldenstaedtii*)		

Initial fish biomass (kg)	10.2	10.2	10.1	6.4	6.4	6.4
Feed (kg/cycle)	5.17	5.10	5.24	3.14	3.24	3.25
Feed type	Coppens SteCo PRIME-17					
Feeding rate (%/BW)	1	1	1	1	1	1
Crops	Oregano (*Origanum vulgare*)			Red Rubin Basil (*Ocimum basilicum var. Purpurascens*)	Thyme (*Thymus vulgaris*)	Parsley (*Petroselinum crispum*)
Duration of production cycle (days)	42	42	42	42	42	42
Crop growing technique	Staggered production					
Crop density (plants/m^2)	62	31	62	31	31	31
Crops individual average yield (g/plant)	10.31	18.77	13.77	13.52	8.20	5.40
LAI (m^2/ m^2)	8.64	5.94	11.44	9.46	0.48	1.66
RGR (g/g/day)	0.046	0.060	0.049	0.068	0.042	0.058
NAR (g/m^2/day)	83.67	172.41	99.32	14.47	511.91	12.82
CGR (g/m^2/day)	0.088	0.172	0.105	0.094	0.043	0.041
Average LAR (cm^2/g)	11.81	9.23	10.44	83.70	1.47	86.73
Working days per year	365	365	365	365	365	365

As it can be notice from table 2, from the technological point of view, the best crop growth performance was achieved by Oregano, followed by Red Rubin Basil, Thyme and Parsley (Table 2), while regarding aquaponics production technique, the best performance was noticed in the ON2 system, followed by the OH1, BN2, ON1, TN2 and PN2. Also, the crop density that yielded the best individual results was 31 plants/m$^{2.}$

However, the best total vegetable biomass yield for one square meter was obtained applying the 62 plants/m^2 crop density. Nevertheless, this higher crop density was not the most popular because of the poor plant welfare and quality.

Acknowledging that the fish feed is only source of nutrients for the plants (beside an occasional chelate iron supplement, when needed), the biochemical composition of the fish feed influences the crop growth process and therefore, the entire system productivity.

In each of the six experiments presented in Table 2, the same type of fish feed – Coppens SteCo PRIME-17– was administered, using a feeding rate of one percent of body mass per day.

Two intermediary biometric measurements were made during the experimental period (after 14 days and respectively, 28 days) and the fish feed quantity was adjusted accordingly using the same ratio. The biochemical composition of the fish feed consisted of: 42% brute protein, 17% fats, 0.9% phosphorus, and a mixture of vitamin A, D3, E and C. The fish feed came in form of three millimeters pellets.

4.2. Economic analysis

The economic analysis, presented below, was performed taken into consideration elements like implementation and production costs, fixed and variable costs, price variation along a production year, monthly income for one cycle of production, gross profit, net profit, rate of profit, production capacity estimation, income estimation for each of the six presented production systems, For each of the two types of aquaponics systems, the implementation costs were calculated (Table 3 and 4).

This was made taking into consideration that different aquaponics techniques generates different implementation costs (Table 3 and 4).

Table 3: Implementation cost for a Media Grow Bed aquaponics system (OH1).

Crt. No.	Requirements for **one** aquaponics module (MGB)			Item Cost (€/1 m^2)
	Items	No. of necessary items	Cost/Item (€)	
1	Pump and electrical wiring (pc.)	1	42	72.72

2	Polypropylene piping (m)	8.5	0.90	13.25
3	Polypropylene fittings (pc.)	6	0.4	4.16
4	Metal fittings (pc)	16	0.9	24.94
5	Valves (pc.)	5	4.5	38.96
6	Hydroponic units – tank (pc.)	3	7.7	40
7	Growing media – 6-12mm L.E.C.A. (L)	75	0.19	24.68
8	Net pots (pc.)	48	0.12	9.97
9	Hydroponic module support (pc.)	1	20.5	35.50
10	Electronic ballast and wiring (pc.)	1	63.11	109.28
11	Metal-Halide 400W lamp (pc.)	1	23.77	41.16
12	Lamp reflector (pc.)	1	12.4	21.47
13	Electrical switch timer (pc.)	1	7.77	13.45
14	L.E.C.A. biological activation system (pc.)	1	35.6	61.65
15	Seedling greenhouse kit (pc.)	1	32.22	55.79
16	Labor (hours)	11	10	190.48
Total cost (€/1 m^2)				**757.46**

It can be clearly observed that the highest implementation costs (for 1 m^2) are represented by labor, followed by electrical components (electronic ballast and wiring, pumps and electrical wiring) and the L.E.C.A. biological activation system. On the other hand, the lowest implementation costs are the polypropylene fittings and piping, and the net pots.

Table 4: Implementation cost for a Nutrient Film Technique aquaponics system (ON1, ON2, BN2, TN2, and PN2).

Crt. No.	Requirements for **one** aquaponics module (NFT)			Item Cost (€/1 m^2)
	Items	Number of necessary items	Cost/Item (€)	
1	Pump and electrical wiring (pc.)	1	42	72.72
2	Polypropylene piping (m)	4.4	0.90	6.86
3	Polypropylene fittings (pc.)	12	0.4	8.31
4	Metal fittings (pc)	16	0.9	24.94
5	Valves (pc.)	5	4.5	38.96
6	Hydroponic units – pipe (pc.)	3	4.62	24
7	Net pots (pc.)	48	0.12	9.97
8	Hydroponic module support (pc.)	1	26.8	46.41
9	Electronic ballast and wiring (pc.)	1	63.11	109.28
10	Metal-Halide 400W lamp (pc.)	1	23.77	41.16

11	Lamp reflector (pc.)	1	12.4	21.47
12	Electrical switch timer (pc.)	1	7.77	13.45
13	Seedling greenhouse kit (pc.)	1	32.22	55.79
14	Labor (hours)	10	10	173.16
Total cost (€/1 m^2)				**664.48**

However, in case of the NFT system, the highest implementation costs (for 1 m^2) are also represented by labor, followed by electrical components (electronic ballast and wiring, pumps and electrical wiring), and the greenhouse kit needed for the plant seedlings, while the lowest implementation costs are the polypropylene fittings and piping, and the net pots, just like in the case of the MGB system.

The initial costs for implementing such aquaponics systems (the MGB and the NFT) might be higher in case of opting for LED lighting. It can be observed that NFT aquaponics systems are less expensive, due to the absence of the needed growing media present in the MGB aquaponics system. Thus the NFT might represent an advantage for investors with a tight or limited budget when choosing a certain aquaponics system. Also maintenance is easier, and thus, cheaper in case of the NFT aquaponics system.

During the experimental periods, both variable and fixed costs were identified, monitored and evaluated. The fixed costs (Table 5) are independent of production output, and do not change, while the variable costs are strongly dependent on production output, and will increase or decrease depending on production scaling.

Table 5: Yearly fixed costs

Crt. No.	Fixed costs per year (€/1 m^2)	**ON1**	**ON2**	**OH1**	**BN2**	**TN2**	**PN2**
1	Depreciation*	332.24	332.24	378.73	332.24	332.24	332.24
2	Provisions for risks and charges**	49.84	49.84	56.81	49.84	49.84	49.84
Total (€/1 m^2)		**382.08**	**382.08**	**435.54**	**382.08**	**382.08**	**382.08**

* calculated for a period of 2 years; ** calculated as 7.5% of implementation costs.

Depreciation accounts for mostly all the fixed costs and depends on the implementation costs, thus the depreciation for the NFT systems is lower than that of the MGB system. A solution for decreasing fixed costs could be to calculate the depreciation over a period of three or more years and/or down warding the percentage for risk and charges provisions. If the business risk assessment recommends it, the provisions for risk and charges could even be eliminated. In order, for a fish farm, to be economically viable, the total costs must comprise, most entirely, of variable costs, rather than fixed costs.

Among the variable costs, fish feed costs are predominant and make up more than 60%. Thus, the fish feed costs are more fairly justified in case of integrating an aquaponics system, because the fish feed is also the nutrient base for the plants.

As it can be noticed in tables 6, 7, and 8 the labor and maintenance costs, in the case of the system that applied the media grow bed technique, is higher because growing the crops in an L.E.C.A. media involves an extra degree of work, such as: preparing the media, activating the media, cleaning and unclogging the media, and disinfecting the media. In the case of the systems where the nutrient film technique was applied, these costs were lower because they did not involve an extra component – the growing media.

The labor and maintenance costs vary depending on the grown plant species, because the plants have different degrees of physiological characteristics, influencing operational activities, such as: the seedling transplanting into the system, day-to-day plant up keeping and harvesting. Because the staggered crop technique was applied, the variable costs were calculated not only for one production cycle, see table 6, but also for the entire first and second years of production, see tables 7 and 8.

Table 6: Variable costs for a production cycle

Crt. No.	Variable costs per production cycle (€/1 m^2)	**ON1**	**ON2**	**OH1**	**BN2**	**TN2**	**PN2**
1	Labor	7.37	5.17	8.37	5.17	5.17	5.17
2	Seeds	1.18	0.59	1.18	0.78	0.35	0.71
3	Electricity	49.75	49.75	51.63	37.30	37.30	37.30
4	Chelated iron	0.77	0.77	0.84	0.67	3.67	1.14
5	Biological activation kit	-	-	0.37	-	-	-
6	Chemical Test Kits for Testing Water Quality	1	1	4.31	1	1	1
7	Maintenance	0.33	0.30	0.44	0.24	0.11	0.03
8	Insurance	1.63	1.49	2.18	1.18	0.55	0.14
Total (€/1 m^2)		**62.03**	**59.07**	**69.32**	**46.34**	**48.15**	**45.49**

The way the staggered crop technique is applied, as described in material and methods (Experimental design and cost-effectiveness method – second paragraph), first and second production year variable costs are different, see Tables 7 and 8. This is because in the first six weeks, of the first year of production, the aquaponics systems do not work at their full production capacity, see Table 7.

Table 7: Variable costs for the first year of production

Crt. No.	Variable costs per 1st year (€/1 m^2)	ON1	ON2	OH1	BN2	TN2	PN2
1	Labor	363.08	254.99	412.37	254.99	254.99	254.99
2	Seeds	58.16	29.08	58.16	38.45	17.25	35.00
3	Electricity	401.46	401.46	416.61	298.84	298.84	298.84
4	Chelated iron	37.81	37.81	41.24	33.16	180.79	56.30
5	Biological activation kit	-	-	18.20	-	-	-
6	Chemical Test Kits for Testing Water Quality	49.10	49.10	212.57	49.10	49.10	49.10
7	Maintenance	16.11	14.66	21.53	11.59	5.37	1.40
8	Insurance	80.54	73.32	107.63	57.97	26.89	7.03
Total (€/1 m^2)		**1006.26**	**860.42**	**1288.31**	**744.10**	**833.23**	**702.66**

Because the aquaponics systems were already running continuously from the end of the first year, full production capacity was achieved for the entire second year of production, as presented in Table 8. It can be noticed from Tables 6, 7 and 8 that the variable cost values in case of the OH1 system, where MGB technique was applied, are higher due to the media activation and the chemical kits needed to test the water during this process. Also, the cost of seeds, chelate iron and maintenance varies depending on the plant species being grown, but seed costs vary also depending on the crop density being applied. The seed costs for ON1 being double than the costs for ON2, since the crop density is also double. Out of all the variable costs, electricity is the most expensive, followed by labor costs, this being the case in both type of aquaponics systems. Electricity costs could be significantly lowered by using LED lamps instead of the high wattage metal-halide lamps.

Table 8: Variable costs for the second year of production

Crt. No.	Variable costs per 2nd year (€/1 m^2)	ON1	ON2	OH1	BN2	TN2	PN2
1	Labor	383.03	269.00	435.03	269.00	269.00	269.00
2	Seeds	61.36	30.68	61.36	40.56	18.20	36.92
3	Electricity	423.52	423.52	439.50	315.26	315.26	315.26

4	Chelated iron	39.89	39.89	43.51	34.98	190.72	59.39
5	Biological activation kit	-	-	19.20	-	-	-
6	Chemical Test Kits for Testing Water Quality	51.80	51.80	224.25	51.80	51.80	51.80
7	Maintenance	16.99	15.47	22.71	12.23	5.67	1.48
8	Insurance	84.96	77.35	113.54	61.15	28.37	7.42
Total (€/1 m^2)		**1061.55**	**907.71**	**1359.10**	**784.98**	**879.02**	**741.27**

Table 9 describes how electricity costs depends strongly on the plant photoperiodicity and thus on the daily lamp operating hours, as can be seen in the case of ON1, ON2 and OH1 where oregano was grown, and the costs are higher, while the costs for BN2, TN2 and PN2 are lower, having less daily lamp operating hours.

Table 9: Electricity costs for each analyzed aquaponics system

Production System	**Electric consumer**	**Power Consumption** (kWh/m^2)	**Operation hours per cycle**	**Cost per cycle** (€/1 m^2)	**Operation hours per year**	**Cost per year** (€/1 m^2)
ON1	Aquaponic module recirculating pump	0.104	1008	11.48	8766	97.77
	MH lamp	0.693	504	38.27	4383	325.75
	Total	**0.797**	**-**	**49.75**	**-**	**423.52**
ON2	Aquaponic module recirculating pump	0.104	1008	11.48	8766	97.77
	MH lamp	0.693	504	38.27	4383	325.75
	Total	**0.797**	**-**	**49.75**	**-**	**423.52**
OH1	Aquaponic module recirculating pump	0.104	1008	11.48	8766	97.77
	MH lamp	0.693	504	38.27	4383	325.75
	Activation system recirculating pump	0.017	1008	1.88	8766	15.98
	Total	**0.814**	**-**	**51.63**	**-**	**439.50**
BN2	Aquaponic module recirculating pump	0.104	1008	11.58	8766	97.87
	MH lamp	0.693	336	25.72	2922	217.39
	Total	**0.797**	**-**	**37.30**	**-**	**315.26**
TN2	Aquaponic module recirculating pump	0.104	1008	11.58	8766	97.87

	MH lamp	0.693	336	25.72	2922	217.39
	Total	**0.797**	**-**	**37.30**	**-**	**315.26**
PN2	Aquaponic module recirculating pump	0.104	1008	11.58	8766	97.87
	MH lamp	0.693	336	25.72	2922	217.39
	Total	**0.797**	**-**	**37.30**	**-**	**315.26**

Regarding the electricity consumption, presented in table 9, the costs vary only due to the photoperiodicity of the plant species and thus due to the different daily operating hours (12/24 hours for Oregano and 8/24 hours for Red Rubin Basil, Thyme and Parsley), and also, in case of the OH1 system, during the media activation process, an extra, smaller, recirculating pump is required. Besides that, the aquaponics system recirculating pump is the only other consumer and its consumption and generated costs are constant across all six systems.

Crop production (Table 10) is the main variable behind the income of the aquaponics systems. The crop production capacity of the six analyze aquaponics systems was reported for one production cycle, but also for both the first and second years of production, because of the applied staggered crop technique, described in material and methods (Experimental design and cost-effectiveness method – second paragraph).

Table 10: Crop production for each analyzed aquaponics system

Crt. No.	Crop production	**ON1**	**ON2**	**OH1**	**BN2**	**TN2**	**PN2**
1	kg/m^2/cycle	0.64	0.58	0.85	0.42	0.25	0.17
2	kg/m^2/1st year	30.03	27.34	40.13	19.70	11.95	7.86
3	kg/m^2/2nd year	33.23	30.25	44.40	21.79	13.22	8.70

Higher productivity was registered in the case of the two systems (ON1 and OH1) where a higher crop density was applied (Table 10). The crop production difference between the first and the second production year observed in Table 10 is due to the implemented staggered technology, where in the first operational year, the first six weeks do not produce any crops.

In order to maximize the RAS profit and in order for the growing of plants to be able to sustain the rearing of fish, as stated by Engle (2010), the market dynamic must be well studied. Thus, it was necessary to analyze the monthly price evolution during an entire production year, for all four plants. The prices were obtained by averaging the recorded European and North American prices for the four plant species we experimented with. According to the market research, the red rubin basil has the highest economic value, followed closely by oregano and thyme, while parsley recorded the lowest values.

In relation to crop production presented in Table 10 and the monthly price variation, see the above table, we were able to determine the monthly income for the first two years of production (Table 11).

Table 11: Monthly income for the first two years of production

Monthly income												
Month	**ON1**		**ON2**		**OH1**		**BN2**		**TN2**		**PN2**	
	1	2	1	2	1	2	1	2	1	2	1	2
1	0.00	174.57	0.00	158.93	0.00	233.28	0.00	135.39	0.00	54.63	0.00	17.17
2	111.17	160.45	101.20	146.07	148.55	214.40	84.60	122.10	36.64	52.88	11.30	16.31
3	150.97	148.57	137.44	135.25	201.73	198.52	112.27	110.48	51.89	51.06	13.41	13.20
4	141.00	138.76	128.37	126.32	188.42	185.42	86.61	85.23	50.23	49.43	9.35	9.20
5	110.45	108.69	100.55	98.95	147.59	145.24	70.86	69.73	37.28	36.69	7.91	7.78
6	83.95	82.61	76.42	75.21	112.18	110.39	54.04	53.18	30.61	30.12	6.77	6.66
7	99.53	97.95	90.61	89.17	133.00	130.88	67.49	66.42	36.82	36.24	7.50	7.38
8	123.20	121.24	112.16	110.37	164.63	162.01	83.74	82.41	44.51	43.80	9.75	9.60
9	148.09	145.73	134.81	132.67	197.88	194.73	100.86	99.25	50.88	50.07	11.71	11.53
10	159.78	157.24	145.46	143.15	213.51	210.11	120.69	118.77	53.65	52.80	14.30	14.07
11	173.63	170.86	158.06	155.55	232.01	228.32	133.81	131.68	54.48	53.61	17.81	17.53
12	193.95	190.87	176.57	173.76	259.17	255.05	149.13	146.76	56.97	56.07	18.19	17.91
Yearly	**1495.71**	**1697.54**	**1361.66**	**1545.40**	**1998.66**	**2268.36**	**1064.09**	**1221.40**	**503.96**	**567.40**	**128.01**	**148.34**

Overall, out of all the four grown plants, oregano proved to be the most profitable, followed by red rubin basil, thyme, and lastly, parsley.

Monthly income variations, charted in Fig. 4, can be observed with highs in the winter months and lows in the summer months, due to the price variations when the four plants are or are not in season. Although, in the first production year, January has a null income and

February has a lower income than expected since these two months coincide with the 42 days that it takes for the systems to yield their first crop in the staggered crop production.

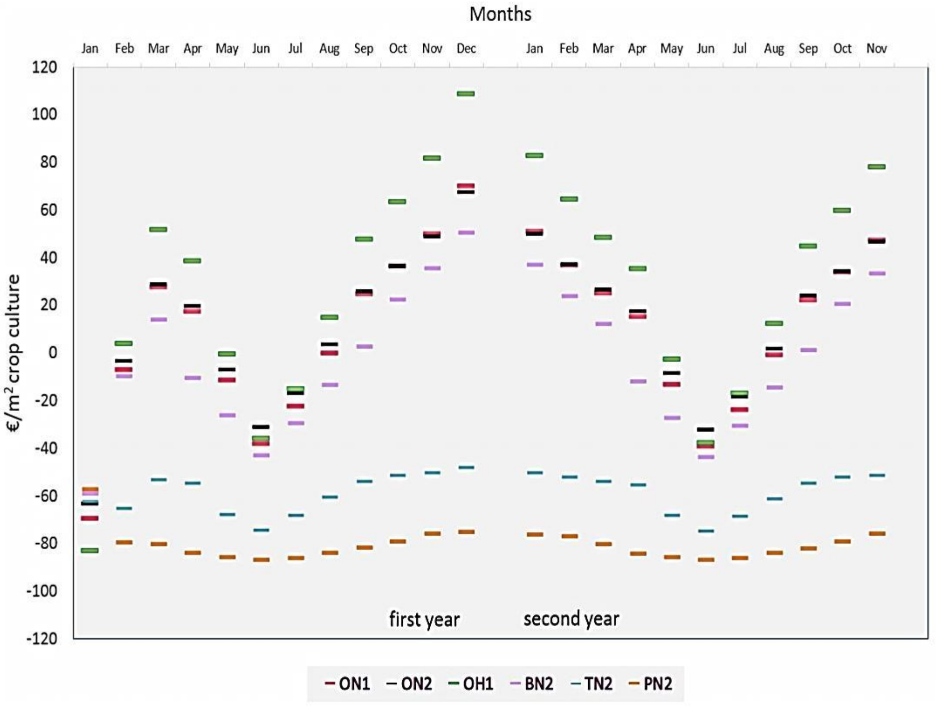


Fig. 4: Monthly income variation over the first and second year of production for each analyzed aquaponics system

After analyzing the economic indicators, it was proven that oregano, grown in both the NFT and the MGB technique and applying both crop densities, is profitable to be grown aquaponically, under our experimental conditions, both in the first year and the second (Table 12) simulated production years, while red rubin basil managed to return a profit only in the second production year.

At the opposite end, thyme and parsley failed to return a profit, the total production costs being higher than the generated income, thus, not being suitable for aquaponics production under the presented experimental conditions.

Out of the four aquaponics systems that turned out to be profitable, OH1 had the highest gross and net profit, return and rate of profit, followed by ON2 and ON1, this being the case for the first production year (Tables 12), and followed by BN2 for the second production year (Table 12).

Table 12: Economic indicators for the first two years of production

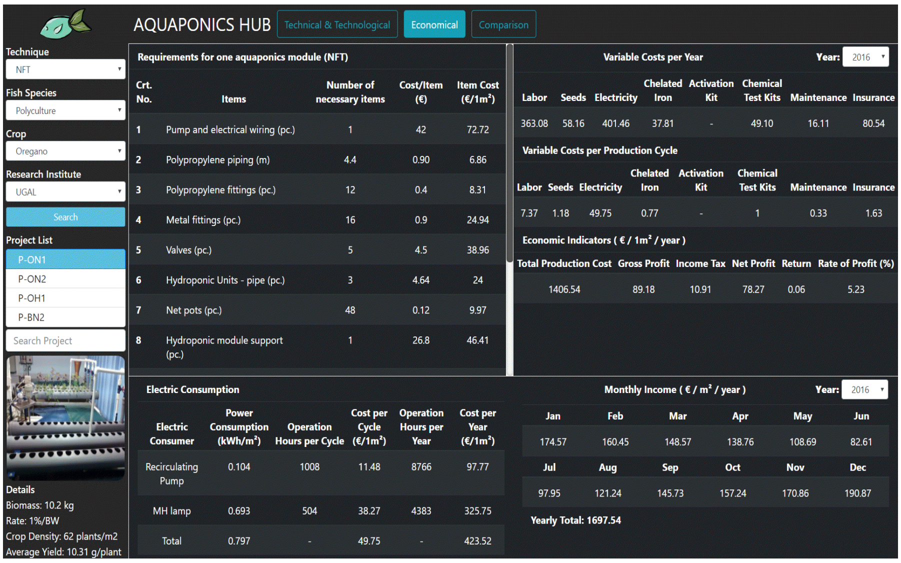
Economic indicators for 1st year	**ON1**		**ON2**		**OH1**		**BN2**		**TN2**		**PN2**	
	1	2	1	2	1	2	1	2	1	2	1	2
Total production cost	1406	1462	1242	1289	1705	1775	1126	1167	1215	1261	1084	1123.35
Gross profit	89.1	234.7	119.1	255.61	293.01	492.92	62.08	54.35	-711.35	-693.70	-956.73	-975.01
Income tax	10.9	12.8	9.9	12.82	16.06	18.82	6.17	8.64	0.00	0.00	0.00	0.00
Net profit	78.2	221.8	109.2	242.79	276.95	474.10	-68.25	45.70	-711.35	-693.70	-956.73	-975.01
Re	0.06	0.15	0.09	0.19	0.16	0.27	-0.06	0.04	-0.59	-0.55	-0.88	-0.87
RPr	5.2	13.0	8.02	15.71	13.86	20.90	-6.41	3.74	-141.15	-122.26	-747.37	-657.29

4.3. Prototyping a technological aquaponics knowledge hub

Even if at the moment recirculating aquaculture systems are on an increasing trend, there were not too many efforts in the direction of building an informational knowledge hub that could help industry players to have a much better understanding over what could be a successful aquaponics system. That is why, based on the research and study presented above, we developed a web based prototype for a knowledge hub that would offer informational integration for anyone interested in sharing relevant aquaponics data obtained from their own research. This kind of tool would be extremely useful for those wanting to start investing in a new system or to validate an already existing research. As such, an Aquaponics Knowledge Hub is meant to provide guidance for better understanding business and operational intricacies of an aquaponics project.

The knowledge this platform provides can be applicable no matter if the aquaponics project is to be operated as a non-profit or for-profit business. The knowledge hub was defined in order to offer support for the following tasks: getting an overview of different aquaponics systems; helping in the organization and management of aquaponics business, sustaining a marketing strategy by identifying most profitable plants to be produced, identifying operational and system architectural insights on system scalability, supporting the financial strategy by providing concrete values for variable costs, economic indicators, energy consumption, incomes.

The aquaponics hub is built around three main perspectives: technical and technological, economical, comparison. On the left side, user have access, no matter what perspective he chooses, to an informational panel where it is possible to specify the characteristics used as input in projects search (Fig.5). User can choose a specified technique, fish species involved in the projects, what type of crop the aquaponics system is aiming and eventually the research institute, organization or the entity that carried out the project (Fig.5).



Technique: NFT
Fish Species: Polyculture
Crop: Oregano
Research Institute: UGAL

Details
Biomass: 10.2 kg
Rate: 1%/BW
Crop Density: 62 plants/m2
Average Yield: 10.31 g/plant

Requirements for one aquaponics module (NFT)

Crt. No.	Items	Number of necessary items	Cost/Item (€)	Item Cost (€/1m²)
1	Pump and electrical wiring (pc.)	1	42	72.72
2	Polypropylene piping (m)	4.4	0.90	6.86
3	Polypropylene fittings (pc.)	12	0.4	8.31
4	Metal fittings (pc.)	16	0.9	24.94
5	Valves (pc.)	5	4.5	38.96
6	Hydroponic Units - pipe (pc.)	3	4.64	24
7	Net pots (pc.)	48	0.12	9.97
8	Hydroponic module support (pc.)	1	26.8	46.41

Variable Costs per Year — Year: 2016

Labor	Seeds	Electricity	Chelated Iron	Activation Kit	Chemical Test Kits	Maintenance	Insurance
363.08	58.16	401.46	37.81	-	49.10	16.11	80.54

Variable Costs per Production Cycle

Labor	Seeds	Electricity	Chelated Iron	Activation Kit	Chemical Test Kits	Maintenance	Insurance
7.37	1.18	49.75	0.77	-	1	0.33	1.63

Economic Indicators (€ / $1m^2$ / year)

Total Production Cost	Gross Profit	Income Tax	Net Profit	Return	Rate of Profit (%)
1406.54	89.18	10.91	78.27	0.06	5.23

Electric Consumption

Electric Consumer	Power Consumption (kWh/m²)	Operation Hours per Cycle	Cost per Cycle (€/1m²)	Operation Hours per Year	Cost per Year (€/1m²)
Recirculating Pump	0.104	1008	11.48	8766	97.77
MH lamp	0.693	504	38.27	4383	325.75
Total	0.797	-	49.75	-	423.52

Monthly Income (€ / m^2 / year) — Year: 2016

Jan	Feb	Mar	Apr	May	Jun
174.57	160.45	148.57	138.76	108.69	82.61
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
97.95	121.24	145.73	157.24	170.86	190.87

Yearly Total: 1697.54

Fig. 5: Aquaponics hub - Economical perspective

Fig. 6:

Technique: NFT
Fish Species: Polyculture
Crop: Oregano
Research Institute: UGAL

Details
Biomass: 10.2 kg
Rate: 1%/BW
Crop Density: 62 plants/m2
Average Yield: 10.31 g/plant

From: 2014 Until: 2017
Parameter: Electricity
Project: P-ON1, P-ON2

From: 2014 Until: 2017
Indicator: Total Production Cost
Project: P-ON1, P-ON2

From: 2015 Until: 2016
Project: P-ON1, P-ON2, P-OH1

From: 2014 Until: 2017
Project: P-ON1, P-ON2

Aquaponics hub - Comparison perspective

The economical perspective view displays important financial information related to the chosen project (fig.5). In the left part, it presents the requirements for one aquaponics module, in our case based on nutrient film technique (NFT), together with variable costs (labor, seeds, electricity, etc) per year or per production cycle (fig.5). Also, it shows the values of the main economic indicators (total production cost, gross profit, income tax, net profit, rate of return, rate of profit), electric consumption costs and monthly income. The platform allows historical data storage for both variable costs and monthly income, so it is possible to choose a reference year, for which the values are shown (fig.5).

The third view of the Aquaponics Hub platform, named “Comparison”, is meant to ease the way different projects can be viewed and analyzed together.

Besides comparing projects, there are also cases where we would like to see the evolution over time for a specific project, according to some criteria’s. The comparison view presented in Fig. 6 makes possible both needs.

As shown in Fig. 6, we proposed four chart areas for displaying single or comparison graphics between projects: variable costs, economic indicators, monthly income, and yearly income. Variable costs panel allows choosing a period, a parameter, one or multiple projects and it will display a yearly comparison between the projects, from the perspective of the selected indicator. Same approach it is also used for the subsequent panels, where user can choose an economic indicator, a period and a set of projects in order to get the comparison charts. Our approach was to define each comparison panel independent from the rest, with its own set of input controls, offering this way the possibility to visualize complex views over the performances for available projects.

5. Conclusions

This article analyzed the cost effectiveness of several IAS where different aquaponics techniques and plant-fish species combinations were applied. The purpose of this study was to demonstrate that aquaponics represents a viable solution for improving RAS profitability. Therefore, after reviewing the literature it was concluded that no studies have been made in order to offer a worldwide solution or “know how” support for prospective aquaculture, especially sturgeon aquaculture, and aquaponics farmers that lack the necessary operating knowledge.

Aquaponics can increase profitability for a recirculating aquaculture system only under the condition of applying specific aquaponics technologies, optimum fish-plant species combinations and also of an efficient technical design. The integration of an aquaponics system maximizes the profit of sturgeon recirculating systems, operating for both sturgeon meat and caviar production and for the replenishing the natural sturgeon stocks through international repopulation efforts. In order to increase economic feasibility, it is recommended the use of efficient electrical consumers (such as LED lamps and intelligent pumps) and also integrating a renewable energy source (such as solar panels). Noticing monthly fluctuations, along a production year, regarding the biomass price per kilogram of a certain plant species, as a result of the demand-offer market variation for that certain plant species, it is recommended the growing of a targeted plant species for a specific period of the year. Combining the solutions presented in this article with the staggered crop production technique has limited to no-effect over the already existing RAS production management. In order to increase net profit and the return, further market research is needed, especially in regard to predicting market demand and identifying possible consumers. Aquaponic products might yield a higher profit if selling directly to different consumers than selling in bulk, or at least in a combination of the two methods, that is why it is important to diversify the consumer portfolio.

This analysis proved that choosing the plant is very important in regards to the profitability of the aquaponics system, therefore oregano and red rubin basil proved to be profitable plants, while thyme and parsley were not. However, thyme and parsley might be profitable under certain technical and technological conditions. The technological aquaponics knowledge hub is important because it can assure the specific aquaponics “know-how”, the complex database being able to provide useful technical and technological support as well as economic assessment, thus reducing the risk margins for the integration of an aquaponics production system. More efforts must be made to promote the existence and purpose of the knowledge hub among researchers to expand the database and therefore to be able to offer more support to future potential investors and aquaponics system developers.

In Romania, studies have shown that the investment for building and operating an aquaponics system depends on the grown varieties and climate. A small-sized aquaponics greenhouse of 1,000 liters, in which can be grown on the average 22 sea basses, would cost Eur 2,000. To this, the operating cost will be added, which would reach to around Eur 280 for each production cycle (about 6 months). If we talk about a business, it would be necessary a Eur 300,000.00 investment for a 2,000-square-meters greenhouse. This business would be profitable if there was a sale insured for the products made in this manner. At the same time, there is also a risk that retailers will not accept organic vegetables that are not well-seeming.

Most often than not, financing or local interests play an important part in making decisions concerning the implementation of high capacity aquaponics systems. Even though the EU are supporting the development of this sector, the legislative framework for aquaponics is not being set aright in most countries.

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