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Improving the Sustainability of Blue Economy through Emerging Aquaponics Techniques and Technologies

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The aim of present study is to identify a suitable aquaponic technique and technology, able to maximize the economic sustainability of the integrated aquaculture systems. Thus, 4 experimental variants were used: AI-SA (imagistic modules+alternative substrate), AI-SH (imagistic modules+conventional substrate), NAI-SA (no imagistic modules+alternative substrate), and NAI-SH (no imagistic modules+conventional substrate). The use of SA can increase the profitability of basil aquaponics systems since it assures similar production performance as SH, but decreases both initial investment and labor costs. The use of AI observation module did not prove to be economic efficient due to the significant increase of initial investment costs.

Keywords: profitability, AI, costs, aquaponics, sustainability.

1. Introduction and analytical context

The European Green Deal Strategic Guidelines reveals the need of improving the sustainability and competitiveness of blue economy through blue farming – aquaculture. Thus, sustainable aquaculture is merging targets as limiting the environmental impact while keeping high production intensity in order to ensure both consumers food security and environmental protection desideratums. Although Romanian aquaculture is mostly based on low intensity pond production systems, in the last decade, investors targeted to establish new rearing infrastructures, capable of supporting high fish stocking densities, as well as to ensure optimum conditions for rearing various fish species, in order to respond to the increasing demand of consumers for allochthonous (non-native) fish species and fish products. These infrastructures, namely recirculating aquaculture systems (RAS), offer the possibility for romanian farmers to extend their distribution chain to international fish markets and improves their competitiveness. However, according to Cristea et al. (2002), the current concerns regarding the diversification and intensification of aquaculture technologies require major investments for establishing the emerging RAS infrastructure. Thus, the adoption of RAS raises many technical and financial problems, especially in terms of rearing various species of sturgeons for meat and caviar, due to long-term production cycle. However, the sturgeon aquaculture production systems play a dual role as follows: ensuring the production of fish for human consumption and reducing the pressure on wild stocks, as well as contributing to restocking activities performed for biodiversity reconstruction programs.

In the context of increasing the intensity of aquaculture production systems, the EU has imposed a rigorous control of this industry from the sustainability point of view. Thus, at national level, in the period 2014-2020, the National Fisheries Strategy, through the direction of action II, aimed to stimulate environmentally sustainable aquaculture, efficient in terms of resource use, innovative, competitive and knowledge-based, desired to be achieved through technical and technological upgrading, investment and innovation, as well as more efficient management of resources. For the period 2021-2030, the European Commission, by its communicate no. 236 / 05.2021, highlights the importance of ensuring the sustainable development of aquaculture, recommending in the action 2.1.7 (adding value to aquaculture activities) and 2.2.1 (environmental sustainability) the practice of multi-trophic aquaculture in order to ensure this desideratum. Thus, the premises for the development of integrated multi-trophic systems are being established, as they might be considered suitable solutions for ensuring the sustainability and profitability of the intensive aquaculture industry. Recent studies (Costache et al., 2021) also indicate a high market opportunity for the integration of multi-trophic aquaponics systems into the green procurement network, both at EU level and especially at national level.

Acording to several authors (Tokunaga et al., 2014, Palm et al., 2014, Palm et al., 2015, Petrea et al., 2016, Petrea et al., 2019, Oniga et al., 2020), integrating aquaponic techniques into already existing RAS systems improves profitability of intensive aquaculture economic activity. However, Xie and Rosentrater (2015) revealed that the profitability of aquaponics integrated systems was found in close relation with the operating scale and price variation. Also, Petrea et al. (2016) made a cost-benefit analysis of several aquaponic technologies, using different combinations of fish-plant species, such as rainbow trout - spinach, trout - spinach, trout - basil, trout - mint and trout – tarragon, concluding the possitive economic effect of integrating aquaponics in aquaculture. Engle (2016) highlights the increase in the profitability of the fish farm in he conditions for the integration of aquaponic technologies for growing biomass of tomatoes, lettuce and basil, respectively, recommending the last plant species mentioned for economic reasons.

In order to increase profitability and to encourage possible investors to integrate multi-trophic production techniques into their fish farms, reducing the investment cost related to the construction and implementation of the aquaponic modules is absolutely necessary. There were studies which analyse the efficiency of all three existing aquaponic techniques (DWC - on floating plates, NFT - on nutrient film and with growth medium), which concluded that both in terms of production and environmental sustainability, the aquaponic technique on growing substrate ensures best performance (Lennard and Leonard, 2006, Sikawa and Yakupitiyage, 2010). In this context, identifying a material with a low purchase price, capable of delivering performance similar to that of the consecrated substrates as hydrotron (light expended clay agregatte) or volcanic rock, must be encourage. Also, the use of artificial intelligence for maximizing the productivity of both fish and plants is recommended since it was used, separately, within aquaculture facilities, by Mathiassen et al. (2011), Zion (2012) and Hufschmied et al. (2011), Odone et al. (2001) for grading, sorting or monitroing the growing performance of biological material. However, the used AI technologies are usualy expensive, increasing the investment costs and the operational costs.

Therefore, the present study aims to identify the effect of ussing AI technologies, as well as alternative shell substrate solutions for improving the economic efficiency of the aquaponics integration process within the RAS fish farms. The results target to reduce the risks of practicing sustainable aquaculture and to improve the competitiveness of already existing fish farms in order to achieve the European Green Deal Strategic Guidelines for Blue Sustainable Economy.

2. Research methodology and infrastructure

2.1. Research infrastructure

An aquaponic Basil (*Ocimum basilicum*) system was integrated within an siberian sturgeon (*Acipenser baerii*) RAS and tested in terms of profitability (fig. 1). The AI technologies, based on Computer Vision and Deep Learning were tested within the estalished aquaponic systems (fig.1). The AI technology consists in 1 image observation modules for plant biomass, composed of 2 x high resolution cameras and 1 x depth camera. The module was integrated within the aquaponic system, as presented in fig. 2. Also, an alternative substrate (AS) was used in order to target the reduction of investment costs.

Fig. 1. Integrated aquaponic system Pilot Station

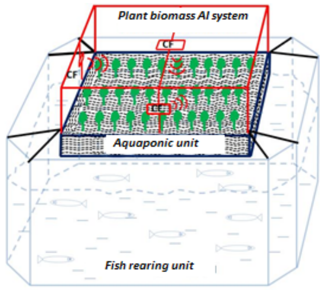

Fig. 2. Representation of Basil AI observation system (CF- foto camera)

2.2. *Experimental design and hyphothesis*

The 1st experimental design consists firstly in testing 2 substrates, a conventional hydroton (light expended clay agregatte) substrate (SH) and an alternative substrate (SA), in order to evaluate their impact on aquaponics profitability. *The hypothesis consists that substrate cost in aquaponics is an important component of initial investment costs. By testing an alternative substrate, initial investment costs are expected to decrease without negatively affecting the plant prodduction.*

The 2nd experimental design consists in testing an aquaponic module with AI observation modules (AI) vs. an aquaponic module without AI observation modules (NAI) in order to identify the impact on a possible integration of AI tested technology on aquaponics profitability. *The hyphothesis consists that AI module will specifically identify possible basil deficiencies during the production cycle, preventing therefore the decrease of plants growing rate and ellimination the risk of obtaining vegetable production no suitable, in terms of quality, for human consumption.*

2.3. Cost-effectiveness analysis formulas

For the cost-effectiveness analysis, the following formulas were used: (1.) $TI = P * Q$, where *TI* = total income (production value), *P* = selling price for 1 kg of biomass obtained by analyzing the market prices for the basil (€/m^2/production cycle) and *Q* = production quantity (g/m^2/production cycle); (2.) $TPC = TFC + TVC$, where *TPC* = total production costs (€/m^2/production cycle), *TFC* = total fixed costs (€/m^2/production cycle) and *TVC* =

total variable costs (€/m²/production cycle); (3.) $Pr = TI - TPC$; where Pr = profit (€/m²/production cycle); (4.) $Re = \frac{Pr}{TPC}$, where Re = rate of return; (5.) $RPr = \frac{Pr}{TI} * 100$, where RPr = rate of profit (profitability ratio) (%).

3. Results and discussions

The technological parameters (tab. 1) revealed that the use of AI basil imagistic observation modules can led to an increase of production with 15.13% if alternative substrate is used, respectively 5.49% in case of using conventional substrate. Also, the synergic use of AI technical solution and alternative substrate will generate a not significant ($p>0.05$) increase of production, with 0.48%, compared to AI+SH experimental variant. However, statistically significat differences ($p<0.05$) are recorded between the two tested substrated, if no AI solution is applied (tab. 1). Thus, in this situation, a decrease of basil production with 7.93% will be recorded in SA variants, compared to the variants where SH was used. These findings confirm that SA can represent a solution for aquaponics, but only if it is used within aquaponic systems with integrated AI imagistic observation modules. However, AI imagistic modules are offering an increse of production due to better plant monitoring and control process.

Table 1: Technical and technological data

Parameter	Experimental variant			
	AI-SA	**NAI - SA**	**AI-SH**	**NAI - SH**
Aquaponic technique	MGB (media growth bed)			
Experimental Variables	Basil imagistic observation modules + Alternative substrate	No basil imagistic observation + Alternative substrate modules	Basil imagistic observation modules + Conventional substrate	No basil imagistic observation modules + Conventional substrate
Lighting luminous flux (lm)	2850			
Lighting wave length (nm)	450-750			
Artificial lighting* (hours/day)	11 violet light for basil growth + 1 hour white light for image collection			
Duration of production cycle (days)	30			
Crop density (plants/m²)	50			
Basil production (g plant/m²)	128.94	112.00	128,32	121.64

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

Within the experimental cycle, the AI module identified iron deficiencies and, therefore, contributed to its proper addition within the aquaponic system. However, plants from NAI experimental variants suffered from deficiencies, situation confirmed by their leaves aspect, at harvesting, as well as by their color histogram.

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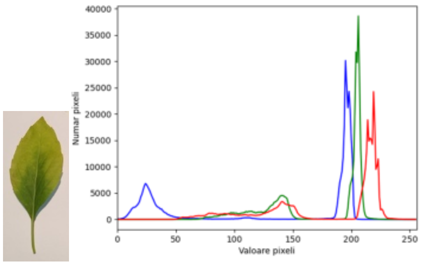

Fig. 3. Basil leaves from NAI experimental variants

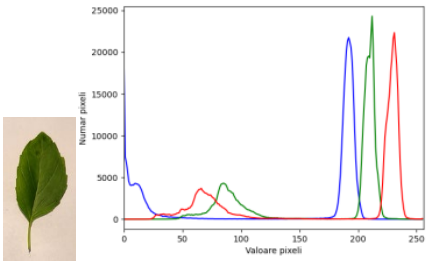

Fig. 4. Basil leaves from AI experimental variants

For the evaluation of implementation cost, only the elements which create differences between the variable were considered. Therefore, it must be highlighted that an AI observation module can cover 4 m^2 of basil culture area. Also, the cost related to conventional substrate was calculated considering a 0,15 m colum of SH within each aquaponic unit. Costs related to SA are due to transport, since its procurement is free.

By analysing the implemetation cost presented in tab. 2, it can be concluded that AI-SH has attributed the highest value (224.56 €/m^2), followed by AI-SA with 173.18€/m^2, NAI-SH (51.38 €/m^2) and NAI-SA (0.29 €/m^2).

Table 2. Implementation cost for a multi-use aquaponics production platform

Main component	Specific components included	Cost of specific component (€)	Cost per m^2 (€)	Total (€/m^2)
AI imagistic observation module	Depth camera	389.95	97.48	173.18
	Microcontroller	107.95	26.98	
	High resolution camera system	113.03	28.25	
	Case	15.71	3.93	
	Microcontroller charger	29,18	7.30	
	Camera support	1.63	0.41	
	SSD card	28.16	7.04	
	White lighting system	7,14	1,79	
Conventional substrate	-	-	51.38	51.38
Alternative substrate*	-	-	0.29	0.29

*included only transport taxes, since it is considered a residue obtained after food processing

According to Petrea et al. (2019), the fixed costs (tab. 3) 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. Thus, it can be observed that the highest amount of fixed costs is associated to AI-SH, respectively AI-SA, mostly due to the depreciation value of AI image observation module.

Table 3. Yearly fixed costs

Crt. No.	Fixed costs per year (€/m^2)	AI-SA	NAI - SA	AI-SH	NAI - SH
1	Depreciation*	17.32	-	17,32	-
2	Provisions for risks and charges**	6.49	0.01	8.42	1.93
Total (€/m^2)		23.81	0.01	25,74	1.93

* calculated for a period of 2 years; ** calculated as 3.25% of implementation costs.

Considering the experimental variables assumed in present study, only 2 variable costs were found to be influenced, namely labor and electricity. Labor costs are the most important in these scenarios since the main advantage of AI image observation system is the ability to limit the time and effort of personnel in charge of operational activities. Therefore, it is estimated that the efficiency of labor was improved with 30% per day per 1m^2 culture surface. Thus, considering this affirmation, it results a 15 hour less labor time per production cycle. Also, the conventional substrate implies a more laborious cleaning operation, compared to the alternative substrate, mostly due to its capacity to absorb water and to its limited exterior surface, thus, an increase specific surface, compared to alternative substrate. However, at the starting of the production cycles, SA could require more time in order to respect the user protocol. Thus, a 20% higher number of hours per production cycle per m^2 was extra attributed to SH for maintenance activity, compared to SA.

The total electricity consumption is revealed in fig. 5. It must be pointed out that the highest consumption is attributed to the server which connects the microcontrollers from the AI image observation module to the interface, followed by the microcontrollers and modem. The white light lamps, which targets to ensure a proper lighting environment for image collection, are operating a period of 1 hour per day, thus recording limited energy consumption. Therefore, it is estimated that the time need for monitoring and control 1m^2 of aquaponics surface is 85.16 hours/year if AI exist and 121.66 h/year in case of NAI. Also, the maintenance of 1m^2 aquaponics surface requires 6 hours/year, while SH demands 7.2 hours/year. Thus, considering these requirements, the variable costs structure (tab. 4) takes into consideration the minimum salary in Romania and reveals the highest labor cost for NAI-SH, followed by NAI-SA, AI-SH and AI-SA. In terms of electricity, it is supposed that the server will connect the entire surface of the aquaponics modules (approximately 3000 m^2 in a minimum surface integrated farm).

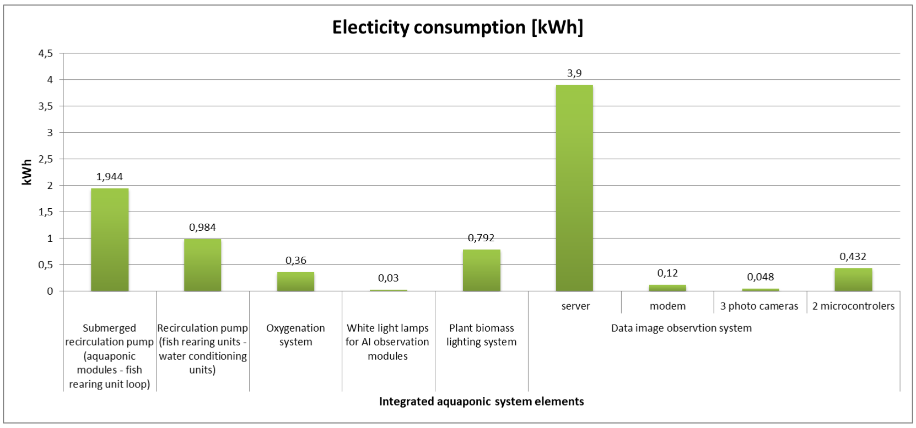

Fig. 5. Daily electricity consumption within integrated aquaponics system (reported to a surface of 4 m^2)

Table 4. Yearly variable costs*

Crt. No.	Variable costs (€/m^2)	AI-SA	NAI - SA	AI-SH	NAI - SH
1	Labor	26.53	37.15	26.88	37.50
2	Electricity	5.75	-	8.60	5.75
Total (€/m^2)		32.28	37.15	35.48	43.25

*no electricity costs are presented at NAI variants since the table only considers electricity consumers which are generated by the induced variables, namely AI data image observation system, in order to evaluate their impact on aquaponic systems profitability.

To maximize the profitability of a multi-use aquaponics production platform, and in order to support the rearing of fish with the help of growing plants, as reported by Engle (2010) and Petrea et al. (2016), the dynamic of the market must be thoroughly studied. Hence, the monthly price evolution for an entire production year was analysed. The colder, winter months, yield the highest profits, while the warm, summer months yield the lowest ones. Using the crop production data (tab.1) and the crop monthly price variation, the income for a production cycle (tab.5) was calculated.

Table 5. Monthly income for a production cycle

Crt. no.	Income (€/m²/cycle)				
	Month	AI-SA	NAI - SA	AI-SH	NAI - SH
1	January	7.31	6.35	7.27	6.89
2	February	6.74	5.85	6.71	6.36
3	March	6.24	5.42	6.21	5.88
4	April	5.35	4.65	5.33	5.05
5	May	4.31	3.75	4.29	4.07
6	June	3.42	2.97	3.41	3.23
7	July	4.10	3.56	4.08	3.87
8	August	4.98	4.32	4.95	4.69
9	September	5.85	5.08	5.82	5.52
10	October	6.61	5.74	6.58	6.23
11	November	7.14	6.20	7.10	6.73
12	December	7.83	6.80	7.79	7.39
Monthly Average		5.82	5.06	5.80	5.49

By analyzing the income scenarios and also, the investment costs, fixed costs and variable costs, it can be observed that NAI variants obtain the highest profit (28.57 €/m²/year at NAISA, respectively 21.10 €/m²/year at NAISH). Also, SA variants are superior in terms of profit, compared to SH variants, situation which confirms the SA utility in term of maximizing the economic efficiency of an basil aquaponics module integrated within a RAS fish farm (tab.6). It is considered that the investment funds are the result of a bank loan, thus, they are included in the total production cost, as fixed costs.

Table 6. Economic indicators for the first year of production

Crt. No.	**Economic indicators**	**AI-SA**	**NAI - SA**	**AI-SH**	**NAI - SH**
1	Total production cost (TPC) (€/1 m²/year)	73.41	37.19	83.68	50.32
2	Gross profit (€/1 m²/year)	2.3	28.57	- 8.33	21.10
3	Income tax (€/1 m²/year)	0.37	4.57	-	3.38
4	Net profit (€/1 m²/year)	1.93	24	-8.33	17.72
5	Return (Re)	0.03	0.76	-	0.42
6	Rate of profit (RPr) (%)	3.03	43.44	-	29.54

The economic indicators indicate that Ai-SH variant did not manage to be profitable in the experimental scenario described in present study. However, according to the results indicated in tab. 6, the NAI-SA is recommended to be implemented if the maximization of profitability is targeted on a short term as a result of integrating the aquaponics techniques, followed by NAI-SH which ensures a 26.16% lower net profit. However, similar to most studies, the design of the current study is subject to limitations. Therefore, the current study did not take into consideration the possible superior nutritional qualities of basil biomass obtained within the experimental variants were AI imagistic observation modules were used. Thus, it is recommended for future studies to take into consideration factors as basil quality and to associate it to a measurable price, for each scenario. Thus, the real benefits of AI technology could be then be better highlighted.

Conclusion

The study concluded that the use of alternative substrate can be a solution in order to increase the profitability of basil aquaponics systems since it assures similar production performance as the conventional substrate, but decreases the initial investment cost, as well as labor costs. Although it decreases the labor costs and slightly increases the production, the use of AI observation module did not proved to be economic efficient, mostly due to the significant increase of the initial investment costs. However, the AI modules could prove to be useful in aquaponics production systems which target a superior crop quality, for a certain niche of consumers.

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