645691 - ECOFISH Project
MSCA-RISE-2014: Marie Sklodowska-Curie

Deliverables 2.2
Establishing Cost-effectiveness of sustainable aquaculture and new market opportunities

One of the most significant worldwide problems is related to assuring that total world food production can cover the needs of each individual, at a certain time and context. Thus, in these circumstances, the agricultural sector gains a considerable attention, given its social and economic implication. In many cases, the growth of agricultural productivity is related with a negative impact on the environment. Therefore, a sustainable development of this production sector is necessary to be made. As Kurtoglu et. al (2010) mentioned, sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional changes in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Also, in the same scientific paper (Kurtoglu et. al, 2010) it is mentioned that sustainable development conserves land, water, plant and animal genetic resources, and is environmentally no degrading, technically appropriate, economically viable and socially acceptable (GESAMP Report, 2001). Three types of sustainability are identified: social, economic and environmental sustainability (Phillips et al, 2001).

Integrating aquaculture recirculating production systems with hydroponics resulted as aquaponics integrated systems, having a double purpose, as follows: obtaining dual production of both fish and plants and assuring a water treatment process by using the phytoremediation capacity of each one of the cultured plant species. Several studies were made during the last decade, in order to evaluate especially the production performances, phytoremediation capacity and economical sustainability of those systems (Petrea et. al, 2013, 2014; Petrea et. al, 2013-A, 2014 –A; Engle et. al 2010; Palm et. al 2014, 2015). Tyson et. al (2011) conclude that aquaponics can be a sustainable agricultural production system.

Love et. al. (2014) mentioned that aquaponic operations vary in size and type of production system and there is a high adoption rate among respondents towards environmentally sustainable methods of production. This fact is reiterated also by Tyson et. al (2011), who underlined the positive impact of aquaponics systems on the market due to public concerns over energy and water use in agriculture.

Water, energy and fish feed are the three largest physical inputs for aquaponic systems (Love et. al. 2014), while the outputs are represented by both fish and plants production.

Several studies (Sotorrio, 2002; Tokunaga et. al, 2014; Palm et. al, 2014; Palm et. al, 2015) had demonstrated that the integration of an aquaponic system into an already existing recirculating aquaculture system represents a good method to increase profitability of the economic activity. Thus, when aquaponics starts to be an economic activity, it implies keeping close eye on costs and production efficiencies throughout the production process. The level of risk in case of aquaponics an integrated system requires the manager ability to make adjustments when negative outcomes occurs, fact that will lead to a successful business (Engle, 2010).

Economic sustainability of aquaponics, the combination of aquaculture and hydroponics, depends on a variety of factors, including system and feed design, animal welfare or parasite and pathogen control (Palm et. al, 2015). Starting from two already productive recirculating aquaculture systems, the aim of present research is to make a comparative cost effectiveness analysis between two integrated aquaponics systems, where both deep water culture (DWC) and light expanded clay aggregate (LECA) substrate aquaponic techniques were applied, in order to identify their economic sustainability.

Integrated aquaponics systems description

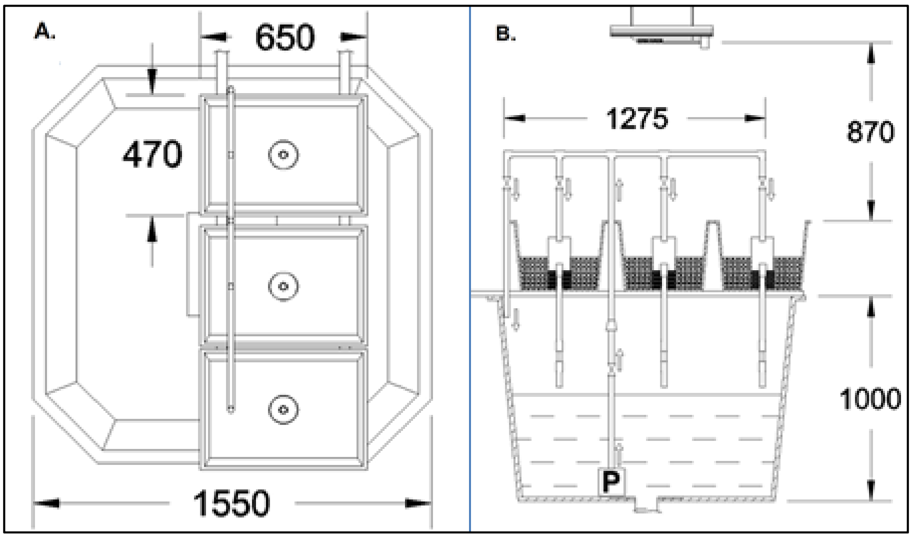
The present experiment took place at the pilot recirculating system stations of Aquaculture, Environmental Science and Engineering Department from Food Science Faculty, "Dunarea de Jos" University of Galati. Two already existed recirculating aquaculture systems were integrated with hydroponic units and other components that ensures water recycling and proper light for plants growth, therefore resulting two aquaponics integrated system, named AQUAP-A and AQUAP-B.

The description in detail of AQUAP-A is presented by Petrea et. al (2014-A, 2014-B), while AQUAP-B si described by Petrea et. al (2013-A, 2013-B). It must be mentioned that two aquaponics techniques were applied as follows: light expanded clay aggregate (LECA) substrate aquaponic techniques (Figure 1) in case of AQUAP-A and deep water culture (DWC) at AQUAP-B (Figure 2).

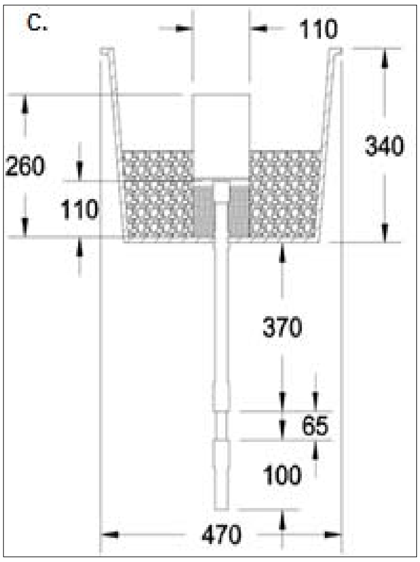
Outside the two above mentioned aquaponics integrated systems, a series of mini-greenhouses for obtaining seedlings were used. Also, in case of AQUAP-A, the biological activation of LECA substrate was made in a mini-system for media biological activation.

Table 1. Experimental design and technological data

	Tehnological Data								
	Aquap-B-BS			Aquap-A-S			Aquap-A-B	Aquap-A-M	Aquap-A-T
Duration of production cycle (days)	44			44			38	38	38
Fish Species	Rainbow trout *(Oncorhynchus mykiss)*			Stellate Sturgeon (*Acipenser stellatus*)					
Initial Fish Biomass (kg)	25.35			31			18.56	18.56	18.56
Feed (kg/cycle)	24			26			8.9	8.9	8.9
Feeding rate (%/BW)	1.5			1.75			1.75	1.75	1.75
Crops	Nores Baby Spinach *(Spinacia oleracea)*			Matador Spinach *(Spinacia oleracea)*			Basil (*Ocimum basilicum)*	Mint (*Mentha piperita)*	Tarragon *(Artemisia dracunculus)*
Culture density (crops/m^2)	BS1	BS2	BS3	S1	S2	S3	74	74	74
	59	48	39	59	48	39			
Crops individual average yield (g)	7.61	9.2	9.88	12.78	14.72	17.12	18.63	16.55	7.9
Working days per year	352			352			352	352	352



A – Top view; B - Aquaponics module cross section



C – Aquaponics unit longitudinal section
Figure 1. LECA substrate aquaponics module

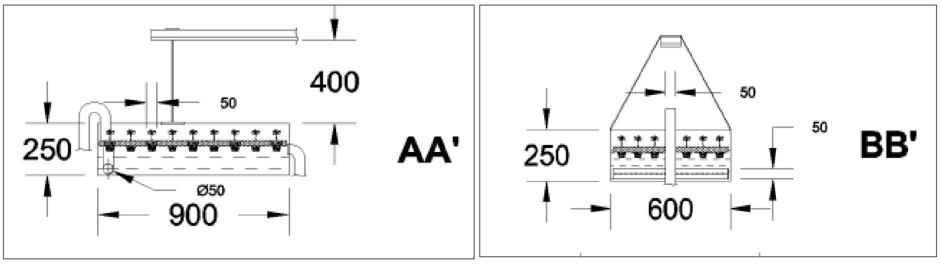


Figure 2. DWC aquaponics unit (AA' - longitudinal section; BB'- cross section)

Experimental design

The integration of two aquaponics modules (AQUAP-A and AQUAP-B) was analysed from cost- effectiveness perspective, by testing five plant species (baby spinach –BS, spinach – S, basil –

B, mint - M and tarragon – T) and also three culture densities (BS1, BS2, BS3 and S1, S2, S3), as presented in table 1.

Formulas:
The following formulas were used:
SpI = TIV / Tpcs, where: SpI= specific investment (€/m²) ,TIV = total investment value (€); Tpcs = total plant culture surface (m²)
TI= PxQ, where: Income= production value; P= selling price for
1 kg of plants (€/m²/production cycle) ; Q=production quantity (g/ m²/production cycle)
TPC=TFC+TVC, where: TPC= total production cost (€/m²/production cycle); TFC = total fixed costs (€/m²/production cycle); TVC = total variable costs (€/m²/production cycle)
Pr= TI –TPC, where: Pr= profit (€/m²/production cycle); TI = total income (€/m²/production cycle); TO = total outcome (€/m²/production cycle)
Re=Pr/TRC, where: Re= return
Rpr=Pr/Ti x100, where: Rpr = Rate of profit (profitability ratio) (%)

Engle et. al (2010) emphasized the economic potential investors concerns for making sure that the systems and technologies used in production process are economic feasible. The main reason of these concerns is to have an idea which is the largest costs for a certain production system or technology.

In order to determine the comparative cost – effectiveness analysis, the capital cost was determined for each of the two tested aquaponics integrated systems: AQUAP-A (Table 2) and AQUAO-B (Table 3).

The capital cost analyses, for the two tested systems, revealed that the applying of LECA substrate aquaponics technique will demand a higher investment cost, compared with DWC technique. The main differences are represented by the costs with growing media and lighting systems. Also, costs that involve water recycling were higher in case of AQUAP-A, where LECA media technique was used, compared with AQUAP-B, where DWC technique was applied (Table 2 and Table 3). Thus, from capital cost analysis (Table 2 and Table 3), it can be conclude that DWC aquaponics technique will gain popularity among those potential investors that have limited capital resources for their first step that implies aquaponics integrated system design and construction.

Table 2. Capital Costs of aquaponic production system **Aquap A (€)**

Items	**No.of necessary units**	**Price/Unit (€)**	**Total Price (€)**
PVC pipes and fittings	50 pieces	0.75	37.5
Valves	4 pieces	4.25	17
Pumps	6 pieces	23.3	139.8
Aquaponic units (durable plastic tanks)	16 pieces	7.2	115.2
Growing media (LECA)	300 L	0.22	66
Mini-system for LECA biological activation	2 pieces	41.6	83.2

Mini-greenhouse for obtaining seedlings	4 pieces	11.4	45.6
Pots and rockwool cubs for seedlings supports	80 pieces	0.11	8.8
Aquaponic units support	12 pieces	7	84
Electronic ballasts	5 pieces	23.9	119.5
Adjust -A-Wings Enforcer reflector	5 pieces	13.4	67
Timer for electrical switch	1 pieces	20	20
Total (€)			**803.6**

Table 3. Capital Costs of aquaponic production system **Aquap B (€)**

Items	**No.of necessary units**	**Price/unit (€)**	**Total Price (€)**
PVC pipes and fittings	6 pieces	0.75	4.5
Valves	4 pieces	4.25	17.00
Pumps	1 pieces	90	90
Aquaponic glass units	4 pieces	33.25	133
Styrofoam plates	4 plates	1	4
Mini-greenhouse for obtaining seedlings	4 pieces	11.4	45.6
Pots and rockwool cubs for seedlings supports	4 pieces	0.11	0.44
Aquaponic units support	4 pieces	5.75	23
Fluorescent lamps	3 pieces	8.23	24.69
Reflector cover	7 pieces	12.13	84.90
Timer for electrical switch	1 pieces	40	40.00
Total (€)			**467.13**

Also, it must be pointed out that costs with aquaponics units, pumping and lighting systems are situated in top three capital costs, in case of both tested systems (Table 2 and Table 3).

The aquaponic production of baby spinach (BS), by using rainbow trout effluent was tested in AQUAP – B, while in AQUAP-A four crops species were tested, as follows: spinach (S), basil (B), mint (M) and tarragon (T) (Table 1). Throughout the experimental period, both fixed costs and variable costs were identified (Figure 3), monitored and evaluated.

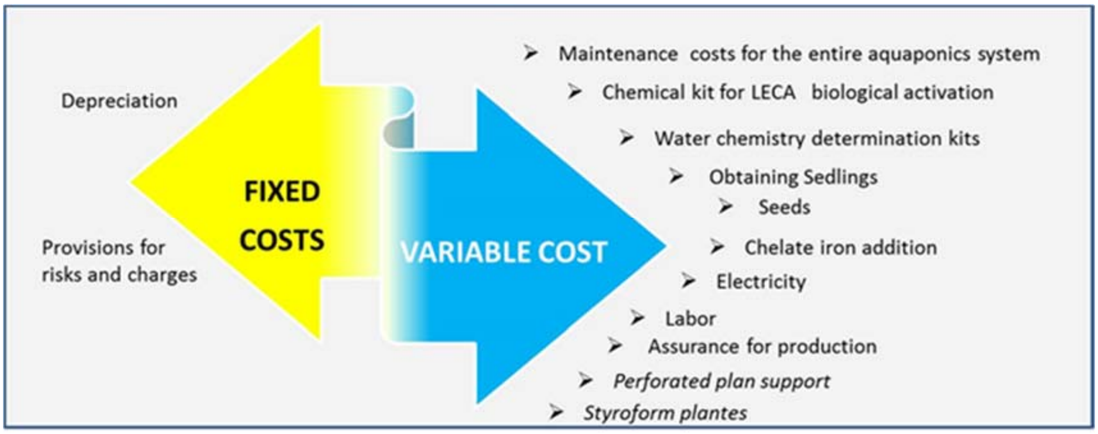


Figure 3: Fixed and variable costs structure for both tested aquaponics integrated system

Therefore, both fixed and variable costs were calculated, following the cost structure presented in Figure 3. The considerations that led to this cost structure were based on the fact that fixed costs are independent of production volume, while variable costs are in direct relation with it.

Amortization has the largest share from fixed costs (Table 4) and depends on capital cost Value. Therefore, the amortization values for BS is lower compared with S, B, M and T (Table 4) because it was cultured by using AQUAP-B system, that has a lower capital cost, compared with AQUAP-A (Table 2 and Table 3).

Table 4: Fixed costs value (€/m^2/production cycle)

	Aquaponic Production Systems				
	Aquap B-BS	*Aquap A-S*	*Aquap A-B*	*Aquap A-M*	*Aquap A-T*
Amortization *	2.4	2.43	2.73	2.73	2.73
Provisions for risks and charges**	0.26	0.37	0.74	1.42	0.71
Total	2.66	2.8	3.47	4.15	3.44

** calculated on a period of 10 years*

*** calculated as 3% of production cycle value*

The variable costs structure value revealed that electricity represents 58.38% in case of AQUAP-B-BS, while higher percentage are registered for AQUAP-A in case of spinach (S) 62.06%, basil (B) 71.57%, mint (M) 66.21% and tarragon (T) 69.74% cultures (table 5).

This is due to the type of lighting systems of each tested aquaponics integrated system: metal-halide (MH) lamps for AQUAP-A and fluorescent lamps for AQUAP-B. Also, the differences between electricity variable cost values registered for S, B, M and T cultures in AQUAP-A are due to different light functioning regime, determined according to each plant species photoperiodicity (table 6).

Table 5. Variable costs value (€/m^2/production cycle)

Production system	*Aquap B-BS*	*Aquap A-S*	*Aquap A-B*	*Aquap A-M*	*Aquap A-T*
Electricity	1.74	3.73	5.16	4.35	4.84
Labor	0.15	0.36	0.21	0.28	0.23
Seeds	0.08	0.11	0.13	0.14	0.13
Chelated iron addition	0.07	0.42	0.23	0.11	0.18
Assurance of production	0.03	0.06	0.06	0.06	0.06
Chemical kit for LECA biological activation	0	0.19	0.11	0.20	0.13
Water chemistry determination kits	0.15	0.43	0.33	0.45	0.39
Maintenance costs for the entire aquaponic system	0.30	0.54	0.54	0.54	0.54
Other costs (styroform plates and perforated plant supports)	0.45	0.34	0.44	0.44	0.44
Total	2.98	6.01	7.21	6.57	6.94

The higher variable cost values, registered at AQUAP –A variants, where LECA substrate technique was applied, is also due to the presence of biological activation process of growing media (LECA), fact which implies costs with chemical kits for biological activation and also an extra quantity of water chemistry determination kits (Table 5). Chelate iron addition generates higher costs in case of AQUAP-A experimental variant (Table 5), most probably because of the aquaponics technique applied. Also, the difference between the experimental variants from AQUAP-A system (Table 5) is due to each plant species predilection for iron absorption. In case of other variable costs, we can mention the styroform plates that are being degraded during the production cycle and must be replaced at the end of it.

Regarding the electricity consumption, we must take into consideration the 8/24 hours photoperiodicity regime of spinach and baby spinach, comparing with mint 11/24 hours, tarragon 14/24 hours and basil 16/24 hours (Table 6). The rest of electricity consumers, like pumps used in aquaponics system and in mini aquaponics system for biological activation and mini-greenhouses for obtaining seedlings, have a 24/24 hours functioning regime.

In order to determine the income, both crops productivity and annually selling price variation were determined and analysed. The best crops productivity per square meter, during a production cycle, was registered in case of the experimental variants where the highest culture density was applied (Table 7).

Table 6. Electricy consumption for analysed aquaponicsystems

Production System	***Consumption Source***	***Quantity ($kWh/m^2/cycle$)***	***Costs (€/m^2/cycle)***	***Functioning Regime (hours)***
Aquap B-BS	Fluorescent lamps	6.53	0.32	8/24
	Pumps used in aquaponic system	24.69	1.21	24/24
	Pumps used in mini aquaponic system	0	0	-
	Mini-greenhouse	4.29	0.21	24/24
	Total	**35.51**	**1.70**	
Aquap A-S	MH lamps	23.67	1.16	8/24
	Pumps used in aquaponic system	31.02	1.52	24/24
	Pumps used in mini aquaponic system	13.88	0.68	24/24
	Mini-greenhouse	7.55	0.37	24/24
	Total	**76.12**	**3.73**	
Aquap A-B	MH lamps	46.94	2.3	16/24
	Pumps used in aquaponic system	31.02	1.52	24/24
	Pumps used in mini aquaponic system	13.88	0.68	24/24
	Mini-greenhouse	13.47	0.66	24/24
	Total	**105.31**	**5.16**	
Aquap A-M	MH lamps	30.41	1.49	11/24
	Pumps used in aquaponic system	31.02	1.52	24/24
	Pumps used in mini aquaponic system	13.88	0.68	24/24
	Mini-greenhouse	13.47	0.66	24/24
	Total	**88.78**	**4.35**	
Aquap A-T	MH lamps	40.41	1.98	14/24
	Pumps used in aquaponic system	31.02	1.52	24/24
	Pumps used in mini aquaponic system	13.88	0.68	24/24
	Mini-greenhouse	13.47	0.66	24/24
	Total	**98.76**	**484**	

Also, it must be taken into consideration that the productivity values registered for B, M and T are also a consequence of applying a 74 crops/m^2 culture density, compared with the highest culture density for S and BS, which was 59 crops/m^2.

Table 7. Crops productivity for all analyzed production systems

Aquaponic system	***Crops production (kg/ m^2/cycle)***	
Aquap A-S	S1	0.75
	S2	0.71
	S3	0.67
Aquap A-B		1.38
Aquap A-M		1.23
Aquap A-T		0.59
Aquap B-BS	BS1	0.45
	BS2	0.44
	BS3	0.39

In order to make aquaponics a source of cash-flow in recirculating aquaculture systems, as it was stated by Engle et. al (2010), the dynamic of the market must be well studied. Therefore, the evolution of prices during a year period, for all five plant species that are analysed in the present research, was made. According with the market research, tarragon has the highest economic value, followed by mint, basil, baby spinach and spinach (Table 8).

It must be mentioned that the price variation presented in Table 8 is for organic plants and it is obtained as an average, after analysing a series of markets that acts both at national and international level. This was made in order to obtain a better image of aquaponics integrated systems economic sustainability, even when there are high variations of marketing strategies and the supply and demand for this crops are in disequilibrium. Price competition is a variable that must also be taken into consideration on long term.

Table 8. Crops annually price variation during
2015-2016 year (€/kg fresh plant)

Month	*Baby spinach*	*Spinach*	*Basil*	*Mint*	*Tarragon*
Feb	15.4	13.2	15.7	20	20.8
Mar	14.6	12.4	15.5	20.2	21
Apr	13.9	11.7	14.9	21.9	20.3
May	13.9	11.7	14.5	18.4	20.2
Jun	13.2	11.1	14.3	18	19.8
Jul	13.7	11.5	14.5	17.5	20
Aug	14.2	12.0	14.9	17.5	20.3
Sep	14.6	12.4	15.3	17	20.8
Oct	15.2	13.0	15.8	18.1	21.1
Nov	15.9	13.6	15.8	18.8	21.5
Dec	16.5	14.2	16.5	18.2	22
Jan	16.9	14.6	16	20	21.7
Average price (€/kg)	**14.8**	**12.6**	**15.3**	**18.8**	**20.8**

In relation to crops productivity (Table 7) and their price variation (Table 8), the monthly income was determined (Table 9).

Table 9. Monthly income for all analysed production systems (€/m^2/cycle)

Aquaponic production systems	**Monthly income (€/m^2/cycle)**												
	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	**Average**
Aquap A-S	9.9	9.4	8.9	8.9	8.3	8.7	9.1	9.4	9.8	10.3	10.7	11.0	**9.5**
	9.3	8.8	8.3	8.3	7.8	8.2	8.5	8.8	9.2	9.6	10.0	10.3	**8.9**
	8.8	10.3	7.8	7.8	7.4	7.7	8.0	8.3	8.7	9.1	9.5	9.7	**8.6**
AquapA-B	21.6	21.4	20.5	20.0	19.7	20.0	20.5	21.1	21.8	21.8	22.7	22.1	**21.1**
Aquap A-M	24.5	24.7	26.8	22.5	22.0	21.4	21.4	20.8	22.2	23.0	22.3	24.5	**23.0**
Aquap A-T	12.2	12.3	11.9	11.8	11.6	11.7	11.9	12.2	12.3	12.6	12.9	12.7	**12.2**
Aquap B-BS	6.9	6.6	6.2	6.2	5.9	6.2	6.4	6.6	6.8	7.1	7.4	7.6	**6.7**
	6.8	6.4	6.1	6.1	5.8	6.0	6.3	6.4	6.7	7.0	7.3	7.5	**6.6**
	5.9	5.6	5.4	5.4	5.1	5.3	5.5	5.6	5.9	6.1	6.4	6.5	**5.7**

Mint growth by using LECA substrate aquaponics technique generates the highest income, followed by basil and tarragon. This situation can be explained by the values of both productivity and especially market price.

Also, on the opposite part, it can be observed that baby spinach aquaponic experimental variant registered the lowest income, fact argued by the small productivity of this plant species, when cultured by using DWC technique (Table 7).

Profit maximization is the objective of every economic activity (Petrea et. al, 2012). This approach is also encountered in other studies related to economic efficiency of aquaponics (Bailey, 1997; Bunyaviroch, 2013; Tokunaga, 2013). In present paper, the main economic indicators of all five experimental variants are presented in Table 10.

Table 10. Economic indicators of all five experimental variants

Production systems	**Total production cost**		**Gross Profit**	**Net Profit**	**Income tax**	**Return**	**Rate of profit (%)**
	(€/m^2/cycle)						
Aquap B-BS	BS1	5.64	1.02	0.82	0.20	0.145	12.3
	BS2	5.64	0.91	0.71	0.20	0.127	10.9
	BS3	5.64	0.08	-0.10	0.17	-0.017	-1.7
Aquap A-S	S1	8.81	0.71	0.43	0.29	0.048	4.5
	S2	8.81	0.11	-0.16	0.27	-0.018	-1.7
	S3	8.81	-0.21	-0.47	0.26	-0.053	-5.4
Aquap A-B		10.68	10.42	9.79	0.63	0.917	46.4
Aquap A-M		10.72	12.30	11.61	0.69	1.083	50.4
Aquap A-T		10.38	1.77	1.41	0.36	0.136	11.6

From the analysis of economic indicators (Table 10), it can be concluded that growing baby spinach at a culture density of 39crops/m^2 by using DWC aquaponics techniques, in technological conditions of present research, is not profitable. Also, growing spinach at culture densities of 39 and 48crops/m^2, by using LECA substrate aquaponics technique, in technological conditions of presented research, is not profitable. Those conclusions are supported by the negative values registered for net profit, return and rate of profit, in previous mentioned cases (Table 10). The income tax was calculated as being 3% of the income value. Also, it must be underlined that, by analysing the gross profit obtained values, only the experimental variant where spinach was cultured at a density of 39crops/m^2 by using LECA substrate aquaponics technique proves to be not profitable.

The values of return economic indicator clearly indicates the cultures of basil and mint, growth a density of 74crops/m^2, by applying LECA substrate technique, as being the best in term of economic profitability.

Considering that there are strong market dynamics over a year, manifested also on price and therefore, on income, there is a necessity for the investors of knowing the fluctuation limits of net profit. Therefore, net profit annual fluctuation was identified and presented in Figure 4.

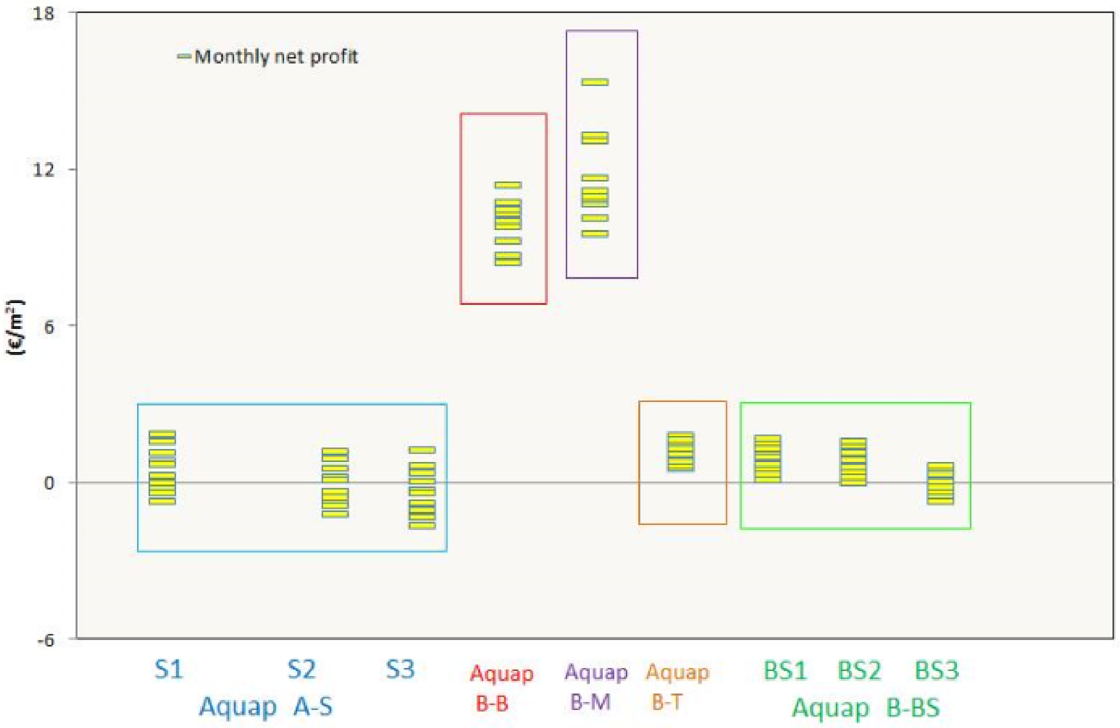


Figure 4. Monthly net profit variation over a year, for each of the experimental variants

Mint culture generates the highest net profit fluctuation over a year, followed by basil and spinach. Therefore, a complex market dynamics prediction is recommended to be made before choosing to growth those plant species in integrated aquaponics systems.

CONCLUSIONS

In conclusion, it can be stated that integrating aquaponics to an already existing recirculating aquaculture system can be a source of cash-flow, if certain plant species, culture densities and aquaponics techniques are applied. This can be widely used especially in case of recirculating aquaculture systems for rearing sturgeons, where the cash-flow distribution in time is less uniform.

Also, another conclusion of the present study is related to electricity costs, which represents more than a half of total variable costs value. Therefore, in order to improve the economic sustainability of the analysed aquaponics integrated systems, there is a strong demand for implementing renewable energy sources.

Regarding plant species, in order to be profitable at the end of each production cycle, over a year, choosing proper plant species for certain target markets is recommended.

However, each aquaponics technique has his particularities, being suitable for certain already purposed capital cost or crop productivity values, fact that helps on choosing best the management practices in recirculating aquaponics integrated systems.

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