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Bio–Economic Study of Freshwater Integrated Multi-Trophic Aquaculture (IMTA) Systems

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Abstract: The Egyptian government focused on developing a strategy to increase fish production through capital intensification by using new technologies for aquaculture production, in which aquaponic represents one of its patterns. In aquaponic systems, plants treat the water by removing the nitrogen and phosphorus resulted from the fish farm and utilizes it for growth as fertilizers so it is recycled rather than being discharged and pollute the environment (to minimize adverse impact of aquaculture to the environment). In the present study, two systems were investigated using Renewable Energy System for sustainability point of view: 1) Integrated Multi-Trophic Aquaculture, IMTA– Nutrient Film Technique (NFT) System. 2) IMTA– Floating Raft System (FRS) in comparison with traditional soil culture system. The present study aims to highlight some of the technical, biological, social and economic features of aquaponic systems in Egypt. The results showed that IMTA–FRS and IMTA–NFT systems achieved best average net income and thus were able to cover costs and achieve economic surplus capacity of 53% and 47% respectively. The results confirm the ability of these two systems to withstand the burden of increased costs of production circumstances or take the risk of falling prices of fish and vegetables (risk reduction). But the transaction was in IMTA–FRS, that the period of recovery of invested capital less (2.17 vs. 3.34 year). One important aim was to conduct the system as a small-scale business unit providing opportunity for youth projects as it represents a national challenge for developing country.

Key words: Aquaponics · Nile tilapia · Economic Development · Hydroponics · Integrated Multi-Trophic Aquaculture

INTRODUCTION

Aquaculture as a business requires a stable run of the cultivation system, maintaining all environmental factors under control. The lack of arable land area and degradation with water scarcity, unlike the challenges associated with climate change are the current problems of agricultural production, especially in the most underdeveloped areas and scarce resources, which should re-evaluate the way in which food is produced. Aquaponics is a concept relatively new to modern food production methods and provides answers to many of the above-mentioned problems [1, 2]. Aquaponics is the cultivation of plants and aquatic animals in a recirculating system. The aquatic animal effluent (typically from fish) accumulates in the water and is rich in plant nutrients, but is correspondingly toxic to the fish. Plants are then grown in hydroponically enabling them to utilize the nutrient-rich water. Thus, the plants take up the nutrients while cleaning the water for the fish. As a closed system, there is little water use, except for what is taken up by the plant for evaporation from the pond and little potential for nutrient waste discharge. A combination of aquaculture and hydroponics as aquaponic system is an amazingly productive way to grow organic vegetables, greens, herbs and fruits. Also, it provides a source of healthy protein in the form of fish as well as fresh fruits, vegetables or herbs [3]. Although the design of aquaponic systems and the choice of hydroponic components as well as fish and plant combinations may seem challenging, but also aquaponic systems are quite simple to operate when fish are stocked at a rate that provides a good feeding rate ratio for plant production [4, 5].

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Blidariu and Grozea [6] reported that aquaponics presents an opportunity to reconsider the indoor fish farming, to bring in more money at the farm gate. Two profit centers for producers: fish and plants. If fish goes through a low cycle then we have ours plant revenue to rely on and vice versa. Aquaponics increase economical efficiency because several key costs, such as nutrients, land and water are substantially reduced; component operating and infrastructural costs are shared. Lower resource requirements extend the geographic range of production to areas that rely heavily on food imports.

There are number of factors that could transform aquaponics from a risky venture with low returns to an economically feasible venture. Increasing the scale of the operation may decrease the proportional cost of capital and operation, thereby making it more profitable. The species constraint could also play a significant role in the viability of the operations. There are only a few economic studies on large-scale aquaponics. Bailey *et al.* [7] conducted an economic analysis of three different sizes of aquaponics system with the optimal production design features. The study found a scale effect; the bigger the system, the higher the rate of return. For this reason, economic feasibility study will help to improve upon these systems.

Rupasinghe and Kennedy [8] studied the economic benefits of aquaponics used the technical and production information from an aquaponic case farm that produces lettuce and barramundi. The results showed that the integrated aquaponic system had a higher economic return and the economic returns especially to prices of lettuce and barramundi.

Therefore the present study is undertaken in an attempt to identify the technical, biological and economic avenues to develop the aquaponics in Egypt as a method of aquaculture. The study also includes social returns associated with the aquaponic systems.

MATERIALS AND METHODS

Experiments were conducted at the El-Kanater El-Khayria- National Institute of Oceanography and Fisheries (NIOF), Egypt) in the fish greenhouse glazing consisted of double layer polyethylene plastics.

System, Renewable Energy Unit, Environment: The integrated recirculating aquaculture and hydroponics system (IRAHS) was constructed based on the technical innovative aspects known in scientific literature. In this system, aquatic animals are cultured separately in an aquatic modular system, which allow the conversion of discharged nutrients into valuable products. Figure 1 displays a diagram of the planned Aquatic animal production and hydroponic systems (IRAHS). The IRAHS consists of three basic units:

One greenhouse (10×24 m^2) with a total area of 240 m^2 as Integrated Multi-Trophic Aquaculture (IMTA) which includes the following:

- A concrete pond of 40 m^3, stocking with low density of Nile tilapia, *Oreochromis niloticus* (15 fish/ m^3).
- A concrete pond of 40 m^3, stocking with high density with Nile catfish, *Clarias gariepinus* (Burchell, 1822) (5 fish/ m^3).

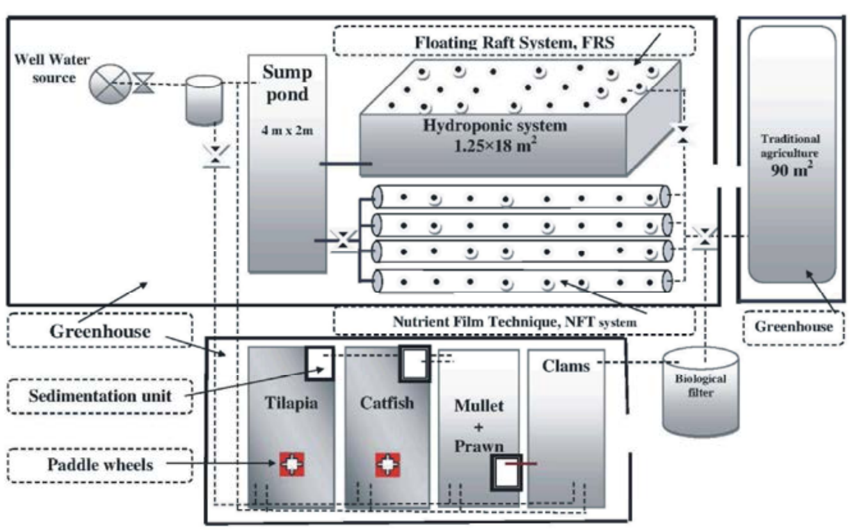

Fig. 1: Schematic diagram of the IRAHS

- A concrete pond of 40 m^3 was used for polyculture of Thin Lipped Grey Mullet (*Liza ramada*) (50 fry/ m^3) and freshwater prawn, *Macrobrachium rosenbergii (de Man 1879)* (84 prawn/ m^3).
- An earthen pond of 40 m^3 was stocking with freshwater clams of *Aspatharia chaiziana* and *Aspatharia marnoi* (Family: *Iridinidae*) (2.5 kg/ m^2). An 8 m3 (4 m x 2m) sedimentation unit for heavy particle removal from tilapia and catfish ponds.

Two greenhouses (7×24 and 7×30 m^2) with a total area of 378 m^2 was used for as horticulture to growing different vegetable species as hydroponics using aquacultural effluents as nutrients, includes 90m^2 dedicated to traditional agriculture for comparison study purposes. All greenhouses were covered by black Thiram 60 microns to protect the fish and plants cultivated from the higher temperature during the summer and lower temperature in winter seasons.

A photovoltaic system (PV) array powers a surface pump that feeds water from the end module of multi-aquatic species greenhouse to hydroponic area.

Two separate IMTA and hydropnic techniques (Nutrient Film Technique, NFT and Floating Raft System, FRS) as aquaponics systems were tested. Construction of the system was based on similar experimental area (20 m^3). In the NFT, Channel slope, length and flow rate were all considered, to make sure the plants receive sufficient water, oxygen and nutrients [1]. The idea for the IMTA-FT system is that a shallow flow of constantly flowing water provides a continuous supply of water, nutrients and oxygen only reaches the bottom of the thick layer of roots that develops in the trough, while the top of the root mass is exposed to the air, thereby receiving an adequate oxygen supply. Channel slope, length and flow rate were all considered and calculated to make sure the plants receive sufficient water, oxygen and nutrients. Meanwhile, in the floating raft system (FRS), plants roots grow directly into a container of water. The rafts provide optimum root exposure to the nutrient water. The styrofoam boards, also shield the water from direct sun light to help maintain lower water temperatures, which is beneficial for plant growth.

Experimental FRS was consisted of a 20 m^2 growing bed with dimensions 20×1× 0.5 m (L × W× D) and lined with a black plastic liner (1 mm thickness). A 5 cm drain was plumbed at the bottom of the West side of each bed. A 7 cm thick hydroponic styrofoam board was cut to the hydroponic bed size and used to float the different plants heads to allow for the roots to be suspended in the water.

In the both of IMTA-NFT (Figure 2) and IMTA- FRS system (Figure 3), the water pumped from the Nile tilapia (40 m^3) and catfish (40 m^3) ponds to the mullet and freshwater prawn pond (40 m^3) and then outflow to the clams pond (40 m^3) then to biological filter and to the hydroponic system and finally recycled again from the end point of either NFT or FRS system to both Nile tilapia and catfish ponds.

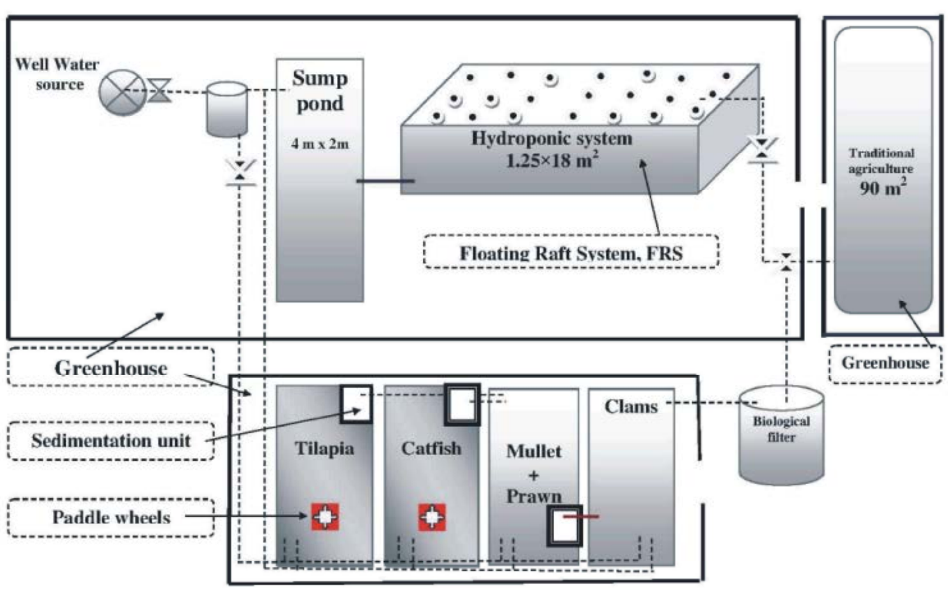

Fig. 2: Schematic diagram of the IMTA-FRS

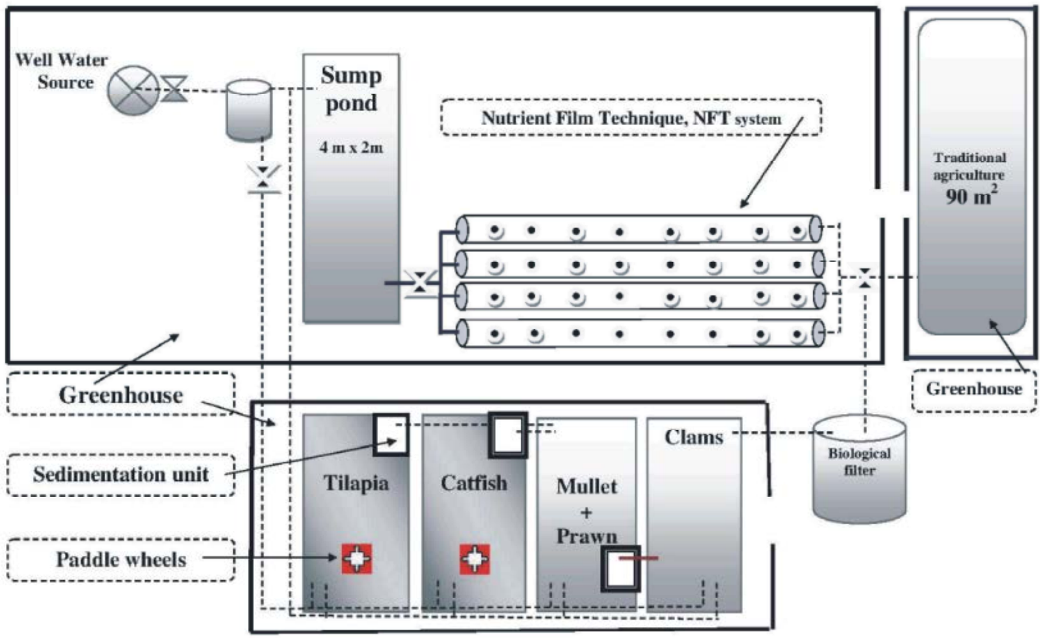

Fig. 3: Schematic diagram of the IMTA-NFT

Water was replenished to each aquaponic treatment system to compensate for water loss from evaporate-transpiration. Water loss was approximately 5% of the system volume per week (0.05% - 1.8% daily). The water in the system cycled from the fish to the plants and back to the fish approximately every 10-15 minutes to assure complete mixing and delivery of fish nutrients to the plants. For each aquaponic system one air diffuser (20 m length) was placed at the bottom of the cylinder to aerate, one air diffuser was placed in each fish pond.

The biological filter contained 80 kg of small polyethylene filter beads topped with 1.8 m^2 of nylon bird netting material. The netting material was manually shaken out inside the filter every week to prevent filters from clogging and overflowing then particulates would dissolve back into solution. The present study is based on data collected and analyzed from the beginning of June 2012 until June 2014. Data were collected on all cost and return items: investment and variable costs, the changing rate of depreciation, annual output of fish and vegetables, selling prices and revenues achieved during the study period. To achieve the goals of the present study has been the use of descriptive, analytical and economic style to study and to elucidate the important technical, biological and economic features for aquaponic systems in Egypt. Also, used some criteria for evaluating the performance [9-11] to know the economics of operating in the current aquaponic systems, including:

Operating ratio (%) = total cost / revenue.

Return on revenue (%) = Net Income / Revenue.

Ratio of costs to revenue (%) = Revenue / Total costs.

Capital payback period (years) = Invested capital / Annual income.

Return on Equity (%) = Net income / Investment.

RESULTS AND DISCUSSION

Literature regarding the financial feasibility of aquaponics as a business is scant. A few models available can be used to help determine the feasibility of an aquaculture or aquaponics venture. Research into the possibility of using available models for the purpose of determining the feasibility of the case study farms concludes that it is not possible to take an existing model and modify it to suit the needs of this study. Aquaponics systems are unique and therefore a unique model must be designed for these case studies. The research uncovered a number of different methods for building models and assisted the author in designing the model for this study.

Table 1: Growth performance of different aquatic species culture in aquaponic system

	FBW	SGR	FCR
Nile tilapia*	191.00±1.3	1.92±0.17	1.69±0.1
Catfish *	668.27±21.0	1.34±0.2	2.00±0.3
Mullets*	86.56±1.02	3.86±0.24	1.68§
Prawn*	18.20±0.77	2.66±0.28	1.65§
Clams*	423.40±60.95	0.73±0.83	1.22§

* IMTA-NFT or IMTA-FRS § An estimate values

Table 2: Production performance of experimental vegetables crops under different aquaponic systems in Egypt

Vegetables	Traditional soil culture	IMTA–FRS	IMTA-NFT
Broccoli			
Total yield weight (TYW, kg/ m²/ 82 days)	2.35	1.27	-
Average weight per unit harvest (AWFH, g/82 days)	313.44	192.41	-
Cucumber			
TYW (Kg / m²/ 46 day)	8.89	5.14	-
AWFH ((g / 64 day)	159.73	108.52	-
Head lettuce			
TYW (Kg / m²/ 145 day)	-	2.84	17.49*
AWFH ((g / 145 day)	-	125.00	139.00
Red leaf lettuce			
TYW (Kg / m²/ 36 day)	-	1.50	12.42*
AWFH ((g / 36 day)	-	96.79	112.03
Green leaf lettuce			
TYW (Kg / m²/ 34 day)	-	1.36	13.20*
AWFH ((g / 34 day)	-	104.62	111.99
Tomato			
TYW (Kg / m²/ 80 day)	6.32	3.58	-
AWFH ((g / 80 day)	130.81	101.36	-
Eggplant			
TYW (Kg / m²/ 80 day)	10.56	6.37	-
AWFH ((g / 80 day)	48.00	20.00	-
Chili papper			
TYW (Kg / m²/ 50 day)	7.33	5.92	-
AWFH ((g / 50 day)	45.82	40.72	-
Bell papper			
TYW (Kg / m²/ 55 day)	7.89	6.11	-
AWFH ((g / 55 day)	59.71	50.36	-
Total Yield Production (kg / m² / year)	43.34	33.73	43.56

* Total of 6 cycles per year

The results indicated that the body weight for Nile tilapia, *O. niloticus* and catfish, *C. gariepinus* were recorded 191.00±1.3g and 668.27±21.0g, respectively. The specific growth rate (SGR, % day) was significantly different in *O. niloticus* (1.92±0.17) and *C. gariepinus* (1.34±0.2). The Annual Biomass Production of 159.79 and 163.58 kg/40m³/6 month are determined for *O. niloticus* and *C. gariepinus*, respectively (Table 1).

In the present fish ponds, mullet's fish and prawns are not offered any feed, but through their feeding activity, swimming and burrowing in the pond, they are re-suspended as a part of the organic particulate matter drain with water from Nile tilapia and catfish ponds. Therefore, feed conversion ratio (FCR) is not estimated. The critical standing crops of 86.56 and 18.20 kg/40 m³ are determined for mullet's fish and prawns in the system, respectively.

Table 3: The most important features of the economic analysis of income and costs for aquaponic systems used in Egypt during the period from June 2011 until June 2014 (calculated as averages annual).

Aquaponic systems	Average production kg/m²*#	Average operating costs (EGP)	Average revenue (EGP)	Average total income (EGP)	Average net income (EGP)
Traditional soil culture	43.34	11447.54	11805.53	357.99	- 948.01
IMTA-FRS	33.73	4065.85	11613.93	7548.08	6242.08
IMTA-NFT	39.84	4065.85	10134.31	6068.46	4762.46

*Type of grown vegetables: Broccoli, Tomato, Eggplant, Chili and Bell pepper, Cucumber, Head lettuce, Red leaf lettuce as well as Green leaf lettuce, Broccoli
#Type of cultured aquatic animals: Nile tilapia, African catfish, Mullet, Freshwater prawn and clams.
One USA Dollar = 7.15 EGP (Egyptian Pound)

Table 4: Economic feasibility criteria for aquaponic systems used in Egypt during the period from June 2012 until June 2014 (calculated as averages annual).

Aquaponic systems	Traditional soil culture	IMTA – FR	IMTA - NFT
Percentage of operation (%)	97.00	35.01	40.12
Return on sales (%)	loss	53.75	46.99
Return on costs (%)	loss	285.64	249.25
Rate of return as a % of total inputs (%)	loss	153.52	117.13

Mullets and prawns were stocked in the system at an average weight of 0.2 g. A clam was stocked in the system at an average of initial weight of 130.18 g and was harvested at a weight of 423.40 g, with survival rate of 76.0%.

In IMTA system a feed conversion ratio (FCR) was recorded as 1.69 for Nile tilapia and 2.00 for catfish (Table 1). Considering that the tilapia and catfish are the only species that were fed in the IMTA system, the improvement impact on apparent FCR values as result of different aquatic species introduced in the IMTA system were not recorded. Since we commenced regular weighing of the fish, we have found the FCR to be 1.22 (estimated). This is lower than the industry standard FCR of 1.5 - 2 for intensively reared tilapia [12] and more efficient usage of feed than in most recirculating aquaculture systems. This is probably because the aquaponic system is in fact an ecosystem in which uneaten food and fish wastes are not removed from the system, but taken up by aquatic organisms and other aquatic microbes, which may then be eaten by the fish. This means that the IMTA system is one of major ways to increase feed utilization in aquaculture.

The three aquaponic systems under study achieved good production rates in terms of vegetables, ranged between 33.73 and 43.56 kg/m^2/year from broccoli, cucumber, head lettuce, red leaf lettuce, green leaf lettuce, tomato, eggplant, chili pepper and bell pepper (Table 2). The present result showed that IMTA-NFT system is suitable for cultivated three varieties of lettuce (head lettuce, red leaf lettuce and green leaf lettuce at six cycles per year) because this system is appropriate only for short-rooted plants. Meanwhile, IMTA–FRS have been cultivated with nine varieties of high nutritional value vegetables during the present study (broccoli, cucumber, head lettuce, red leaf lettuce, green leaf lettuce, tomato, eggplant, chili pepper and bell pepper).

The most important features of the economic analysis of income and costs for aquaponic systems used in Egypt during the period from June 2012 until June 2014 (calculated as averages annual) are shown in Table (3). The results showed that IMTA-FRS achieved the best average net income (6242 EGP/120 m^2) compared to other systems. This is due to mainly the superiority of this system in the production of fish and vegetables as a result of improved water quality in the ponds at a higher rate than other systems except IMTA-NFT system. The differences in water quality were slightly significant ($P>0.05$) and it came second in the ranking (4762.46 EGP /120 m^2) and thus were able to cover costs and achieve economic surplus capacity. Mayer [13] reported that, the proper management of pond water quality plays a significant role for the success of aquaculture operations. Traditional soil culture system has achieved economic loss may be due to a decline in revenue compare to IMTA-FRs system.

Using some criteria such as percentage of operation (%), return on sales (%), return on costs (%) and rate of return as a % of total inputs (%) according to Scott, Muir and Robertson and Helal and Essa [9, 10] for evaluating the current performance of three aquaponic systems (Table 4) showed that operating ratio is considered one of economic efficiency parameters for the use of fixed and variable assets and illustrates the ability of systems to service their cash obligations for the production process. Low percentage for one shows the acceptable economic terms the farm Scott, Muir and Robertson and Holliman [9, 11]. Operating ratio was less than one in all aquaponic systems. This confirms that these systems are economically acceptable, although in IMTA–FRS and IMTA–NFT systems the production process is going efficiently other than traditional soil culture system, because it possess the lowest operating ratio values (35.01% and 40.12% respectively).

Return on sales is one of the administrative and technological proficiency parameters. Whenever this ratio increase this indicates administrative capacity at reduced costs or increased production volume [4]. This ratio was highest in IMTA–FRS (53.75%) than in other systems. This explains that, the economic surplus represents 53.75 of the total revenue followed by IMTA–NFT (46.99%), while the traditional soil culture system has achieved economic loss. These results confirm the ability of IMTA–FR system to bear the burden of increased costs of production much more than other systems.

Rate of return as a percent of total inputs shows the profit of the currency investing [4, 9]. This ratio was also highest in IMTA–FRS (153.52%) than other systems. This indicates the efficiency of this system to achieve high profit Egyptian pounds investor.

Social returns focus in providing job opportunities for youth after training and increase their knowledge and passion for fish and agricultural production, which would lead to its distance from the abnormal behavior as a national goal. As for, the environmental impact of integrated fish culture with plants (vegetables) is based on the awareness of not polluting the water in streams, reusing drainage water ponds after biological treatment by plants.

CONCLUSION

From the previous results, it can be concluded that compared to terrestrial agriculture, hydroponics is generally believed to be more profitable. IMTA–FRS and IMTA–NFT are economically profitable and the revenue could cover the costs of production, but the appropriate system was IMTA–FRS is more productive, also high social and economic profitability. There is a relationship between the size of the system and the price. The smaller, less expensive systems are for home use, while the large, more expensive systems, which are for commercial use. In addition to startup costs, which include the system and the equipment, the user should take into account the costs associated with labor; construction and cost related to building and permitting, maintenance, energy use, fish and fish feed, crops and transportation. As such, the only way to accurately calculate these costs would be to analyze a specific system. The aquaponic system will be more cost-effective if fish feed can be cost-effectively produced through the use of locally feed ingredients or by-product.

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