Turkish Journal of Fisheries and Aquatic Sciences 15: 525-532 (2015)

www.trjfas.org
ISSN 1303-2712
DOI: 10.4194/1303-2712-v15_2_40

Bio Economic Features for Aquaponic Systems in Egypt

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Received 05 January 2015
Accepted 10 July 2015

Abstract

In aquaponic systems, plants treat the water by removing the nitrogen and phosphorus resulting from the fish farm and utilize it for growth as fertilizers so it is recycled rather than being discharged and polluting 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 study aims to highlight some of the technical, biological, social, and economic features of aquaponic systems in Egypt. 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 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) was confirmed by the results. However, IMTA–FRS can be considered as a successes aquaponic model, that the period of recovery of invested capital less (2.17 vs. 3.34 year). Our 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 countries.

Keywords: Aquaponics, tilapia, economic development, hydroponic, integrated multi-trophic aquaculture.

Introduction

The lack of arable land area and degradation with water scarcity, are the current problems of agricultural production, especially in the most under developed areas and scarce resources, which should re-evaluate the way in which food is produced. Aquaculture in the desert and arid regions must be based on the use of as little freshwater as possible due to the limited rainfall and available freshwater sources. In land-based fish culture, water quality may be controlled by a high rate of both water exchange, which is costly or water treatment and subsequent recirculation, which comes at a price. To offset treatment cost, the integrated aquaculture, and plants offers an ideal solution to reduce nutrient discharge levels, increase profitability, and convert the excretion of fish culture into valuable products. Aquaculture as a business requires a stable run of the cultivation system, maintaining all environmental factors under control. Aquaponics is relatively new concept to modern food production methods and provides answers to many of the above-mentioned problems (Rakocy *et al.*, 2006; Essa, *et al.*, 2008). It is defines as 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 then grow hydroponically enabling them to utilize the nutrient-rich water. Thus, the plants take up the nutrients meanwhile 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. In addition, it provides a source of healthy protein in the form of fish as well as fresh fruits, vegetables or herbs (Graber and Junge, 2009). Although the design of aquaponic systems and the choice of hydroponic components as well as fish and plant combinations may seem challenging, but quite simple aquaponic to operate must be chosen where the fish is stocked at a rate that provides a good feeding rate ratio suitable for plant production (Goodman, 2011; Goda *et al.*, 2014).

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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 (Blidariu and Grozea, 2011). Aquaponics increase economic 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.

Increasing the scale of the operation is one of major factors that could transform aquaponics from a risky venture with low returns to an economically feasible venture and 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.* (1997) 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 (2010) studied the economic benefits of aquaponics using technical and production information from an aquaponic case farm that produces lettuce and barramundi. Their results showed that the integrated aquaponic system had a higher economic return and the economic returns especially to prices of lettuce and barramundi.

The Government of the Egypt 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. 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 during the period from June 2012 until June 2014.

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:

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

• An concrete pond of 40 m^3, stocking with low density of Nile tilapia, *Oreochromus niloticus* (15 fish/ m^3).

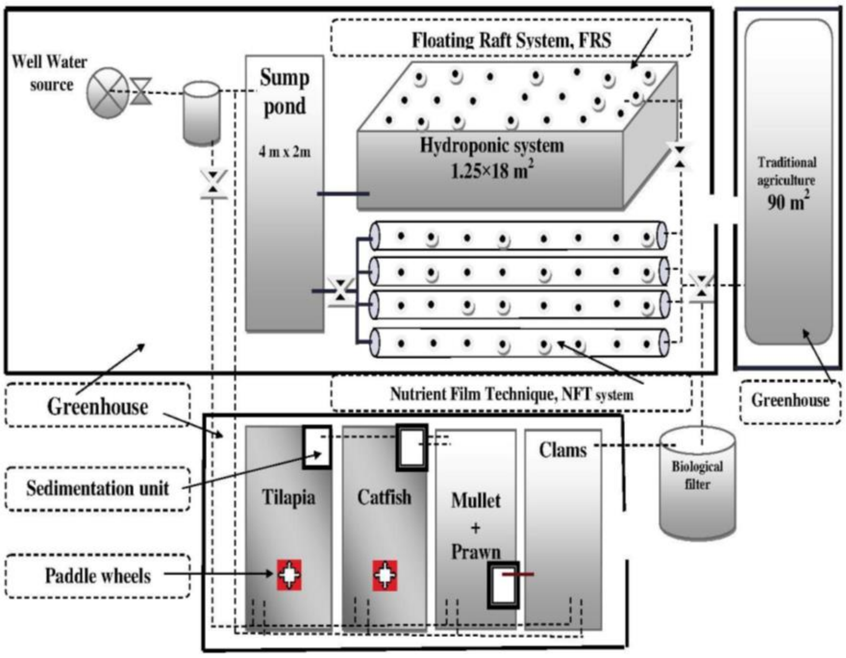

Figure 1. Schematic diagram of the IRAHS.

• A concrete pond of 40 m^3, stocking with high density with Nile catfish, *Clarias gariepinus* (Burchell, 1822) (5 fish/ m^3).

• 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 m^3 (4x2 m) sedimentation unit for heavy particle removal from tilapia and catfish ponds.

Mean final body weight (FBW) was determined by dividing total fish weight in each pen by number of fish. Specific growth rate (SGR) and feed conversion ratio (FCR), were calculated using the following equations:

$$SGR = (\ln FBW - \ln IBW)/t \times 100;$$

where: FBW is final body weight (g); IBW is initial body weight (g); ln= natural logarithmic; t = time in days

$$FCR = \text{Feed intake (g)/weight gain (g)}$$

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 fed on organic particulate matter drain with water from Nile tilapia and catfish ponds. Therefore, feed conversion ratio (FCR) was not estimated.

b) Two greenhouse (7×24 and 7×30 m^2) with a total area of 378 m^2 were used for horticulture to grow different vegetable species as hydroponics using aquaculture effluents as nutrients, includes 90 m^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.

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

Two separate IMTA and hydroponic 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 (Rakocy *et al.*, 2006). The idea for the IMTA-NFT system is that a shallow flow of constantly flowing water providing a continuous supply of water, nutrients, and oxygen which 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 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

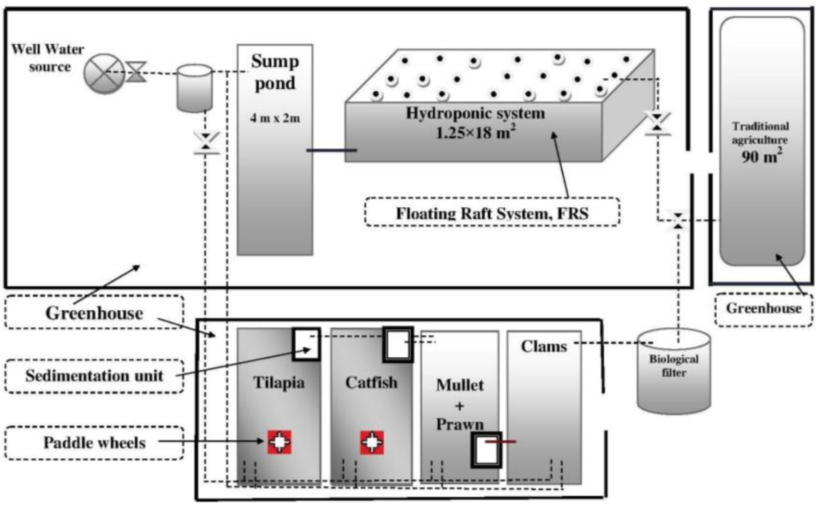

Figure 2. Schematic diagram of the IMTA-FRS.

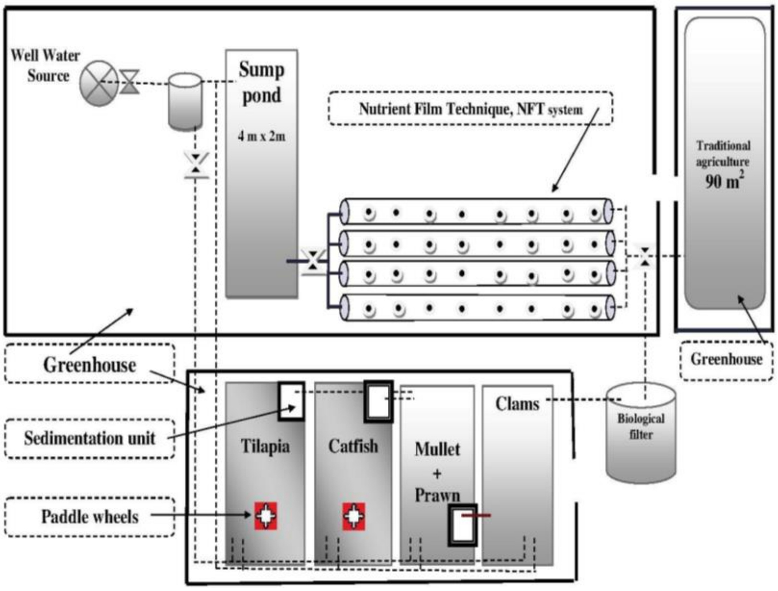

Figure 3. Schematic diagram of the IMTA-NFT**.**

filter, 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.

Water was replenished to each aquaponic treatment system in order 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 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 was necessary. Also, used some criteria for evaluating the performance (Scott *et al.*, 1993; Helal and Essa, 2005; Holliman, 2006) 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 revenue to costs (%) = Revenue/Total costs.

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

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

Results and Discussion

The results indicates that the critical water parameters are very important in the aquaponic system including temperature, pH, dissolved oxygen (DO) and ammonia, which influence the physical properties and chemical composition of the water, and thereafter its correct management can improve the overall fish and plant performance (health and growth). Lethal effects of nitrite (NO_2), nitrate (NO_3), and alkalinity on the fish at high concentrations of this parameters are not common, but their accumulation can affects directly and indirectly the fish growth. However, as the soluble nutrients component contributes to water EC, the present EC values (Figure 4) results observed that NH_4, NO_2, NO_3 and PO_4 were depleted faster in aquaponics nutrient solution than in the beginning of the experiments due to plants growth.

The results of growth performance and feed utilization of the cultured organisms including Mean final body weight (FBW), Specific growth rate (SGR, %/day), and feed conversion ratio (FCR) were shown in Table 1. The higher FBW and SGR for Nile tilapia were found in IMTA system compared to Nile tilapia-FR monoculture system due to the different in fish density in m^3**.** IMTA system total biomass recorded the highest values per m^3 compared to Nile tilapia-RS monoculture system (Figure 5, Figure 6). The same trend was observed for SGR. The body weight for

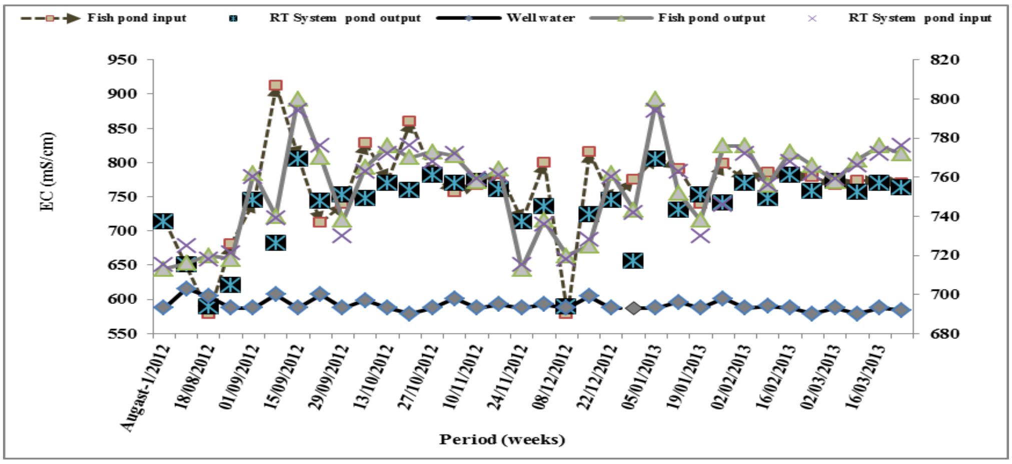

Figure 4. The average electrical conductivity (EC, mS/cm) in Nile tilapia-FRS system during the period from 1-8-2012 to 31-3-2013.

Table 1. Growth performance of different aquatic species culture in aquaponic system (Year 2)

	IBW	FBW	FCR	SGR	Annual Biomass (kg/month)
Low Nile tilapia density*	25.4 ±4.7	231.33±2.31[a]	1.69±0.1[a]	1.38±0.28[a]	127.6[b]
High Nile tilapia density**	25.4 ±4.7	184.06±8.12[b]	1.80±0.2[b]	1.24±0.38[b]	327.63[a]
Catfish *	173.27±17.6	705.65±60.24	2.00±0.3	0.88±0.14	136.90
Mullets*	0.20±0.01	96.76±1.88	1.68	3.86±0.24	96.76
Prawn*	0.28±0.01	19.67±0.87	1.65	2.66±0.28	19.67
Clams*	130.18 ±15.2	415.33±60.95	1.63	0.73±0.83	171

* IMTA-NFT or IMTA-FRS, **Nile tilapia-FR system, §an estimated values.
IBW: Initial body weight, FBW: Final body weight, SGR: Specific growth rate, FCR: feed conversion ratio

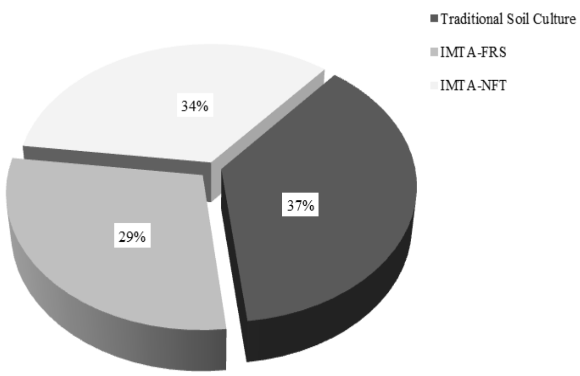

Figure 5. Average percentage of vegetables (Broccoli, Tomato, Eggplant, Chili and Bell pepper, Cucumber, Head lettuce, and Red/Green-leaf lettuce) and animal (Nile tilapia, African catfish, Mullet, Freshwater prawn and clams) productions in different aquaponic systems.

Nile tilapia, *O. niloticus* and catfish, *C. gariepinus* were recorded 184.06±8.12 g and 705.65±60.24 g, respectively. The specific growth rate (SGR, % day) significantly different in *O. niloticus* (1.24±0.38) and *C. gariepinus* (0.88±0.14). The Annual Biomass Production of 327.63 and 136.90 kg/40 m^3/6 month is determined for *O. niloticus* and *C. gariepinus*, respectively (Table 1).

In the present study, the critical standing crops of 96.76 and 19.67 kg/40 m^3 are determined for mullet's fish and prawns in the system, respectively. 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 415.33 g, with survival rate of 73.0%.

In IMTA system, Feed conversion ratio (FCR) was recorded as 1.69 and 1.8 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 because of different aquatic species introduced

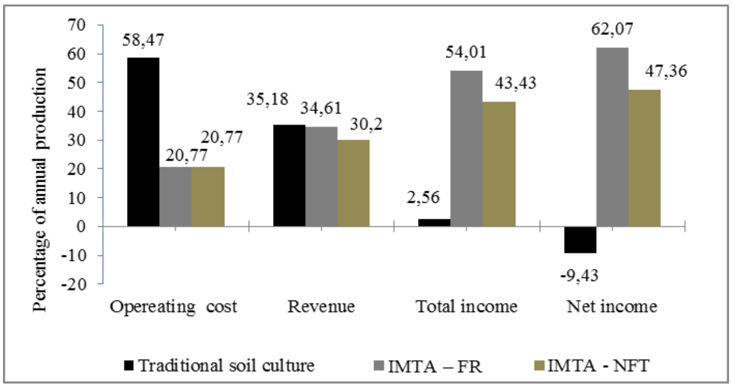

Figure 6. The most important features of the economic analysis of income and costs for aquaponic systems used in Egypt during the period from June 2011 until June 2014 (calculated as averages percentage of annual production).

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 (Stickney, 2005), and demonstrates a 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 present result showed that IMTA-NFT system is suitable for cultivation of three varieties 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 (Table 2). Meanwhile, IMTA–FRS have been cultivating 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).

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 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. Aquaculture and 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.

The production of both vegetables animals as well as the economic analysis including income and costs for aquaponic systems used (calculated as averages annual) is shown in Figure 5, Figure 6. The results showed that IMTA-FRS achieved the best average net income (6242 EGP/120 m^2) compared to other systems, due to mainly the superiority of this system in the production of fish and vegetables because 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 in the second rank (4762.46 EGP/120m^2), and thus were able to cover costs and achieve economic surplus capacity. Mayer (2012) 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.

In the present study, 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 operating ratio shows the acceptable economic terms the farm (Scott *et al.*, 1993; Helal and Essa, 2005, Holliman, 2006). Operating ratio (Table 3) 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 (Goodman, 2011).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–FRS 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 (Scott *et al.*, 1993; Goodman, 2011). 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.

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/ m^2/ 82 days)	2.35	1.27	-
Average weight bear unit harvest (AWFH, g/82 days)	313.44	192.41	-
Cucumber			
TYW (Kg / m^2/ 46 day)	8.89	5.14	-
AWFH ((g / 64 day)	159.73	108.52	-
Head lettuce			
TYW (Kg / m^2/ 145 day)	-	2.84	17.49*
AWFH ((g / 145 day)	-	125.00	139.00
Red leaf lettuce			
TYW (Kg / m^2/ 36 day)	-	1.50	12.42*
AWFH ((g / 36 day)	-	96.79	112.03
Green leaf lettuce			
TYW (Kg / m^2/ 34 day)	-	1.36	13.20*
AWFH ((g / 34 day)	-	104.62	111.99
Tomato			
TYW (Kg / m^2/ 80 day)	6.32	3.58	-
AWFH ((g / 80 day)	130.81	101.36	-
Eggplant			
TYW (Kg / m^2/ 80 day)	10.56	6.37	-
AWFH ((g / 80 day)	48.00	20.00	-
Chili papper			
TYW (Kg / m^2/ 50 day)	7.33	5.92	-
AWFH ((g / 50 day)	45.82	40.72	-
Bell papper			
TYW (Kg / m^2/ 55 day)	7.89	6.11	-
AWFH ((g / 55 day)	59.71	50.36	-
Total Yield Production(kg /m^2/ year)	43.34	33.73	43.56

* Total of 6 cycles per year

Table 3. Economic feasibility criteria for aquaponic systems used in Egypt during the period from June 2012 until June 2014 (calculated as annual averages)

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

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.

Research into the possibility of using available models for 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. Aquaculture and aquaponics systems are unique, and therefore a unique model must be designed for these case studies. The results 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 as it is more productive, also high social and economic profitability. Considering the relationship between system size and total investment needed, the results suggested that smaller, less expensive systems are for home use, while the large, more expensive systems, 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 with locally feed ingredients or by-product.

Acknowledgements

The research was performed within IRAHS project, which was financially supported, by the Science & Technology Development Fund (STDF), Ministry of Scientific Research, Egypt. (Agreement No 2252/ Fishery and Aquaculture Production), Integrated farms for fish production. The authors are grateful for all the support.

References

Bailey, D.S., Rakocy, J.E., Cole, W.M., Shultz, K.A. and St Croix, U.S. 1997. Economic analysis of a commercial-scale aquaponic system for the production of tilapia and lettuce, in: Tilapia Aquaculture: Proceedings of the Fourth International Symposium on Tilapia in Aquaculture, Orlando, Florida: 603–612.

Blidariu, F. and Grozea, A. 2011. Increasing the Economical efficiency and sustainability of indoor fish farming by means of aquaponics – Review. Animal Science and Biotechnologies, 44 (2): 1-8.

Essa, M.A., Goda, A.M.A-S., Hanafy, M.A., El-Shebly, A.A., Mohamed, R.A. and El-Ebiary, E.H. 2008. Small-scale fish culture: guiding models of aquaponics and net-enclosures fish farming in Egypt. Egyptian Journal of Aquatic Research, 34(3): 320-337.

Goda, A.M.A., Essa, M.A. Hassaan, M.S. and El-Sherif, M. 2014. Integrated aquaculture and hydroponics system using renewable energy: I. Fish performance & nutrients flow.Aquaculture America 2014 Conference, February 9-12, Seattle, Washington, USA.

Goodman, E.R. 2011. Aquaponics: Community and Economic Development. MSc thesis, Boston: Massachusetts Institute of Technology, Department of Urban. USA

Graber, A. and Junge, R. 2009. Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production. Desalination, 246(1–3): 147–156. doi:10.1016/j.desal.2008.03.048

Helal, A.M. and Essa, M.A. 2005. Evaluation and bio-economic study of marine cage culture in the west-northern shore of the Mediterranean Sea, Egypt. Alexandria Journal of Agricultural Research, 50(1): 1–9.

Holliman, J.B. 2006. An economic analysis of integrating hydroponic tomato production into an indoor recirculating aquacultural production system. MSc thesis, Graduate Faculty of Auburn University, Auburn, Alabama.UK

Mayer, E. 2012. Monitoring Pond Water Quality to Improve Production.Biomin, June 15, 2012.

Rakocy, J.E., Masser, M.P. and Losordo, T. M. 2006. Recirculating aquaculture tank production systems: aquaponics - integrating fish and plant culture. Southern Regional Aquaculture Center, 454: 1-16.

Rupasinghe, J.W. and Kennedy, J.O. 2010. Economic benefits of integrating a hydroponic-lettuce system into a barramundi fish production system. Aquaculture Economics and Management, 14: 81–96. DOI: 10.1080/13657301003776631

Scott, D.C.B., Muir, J.F. and Robertson, D.A. 1993. Feasibility study of two offshore cage systems for the production of sea bream in the Mediterranean. In: Proc. World Aquaculture Society Conf., Torremolinos, Spain.

Stickney, R.R. 2005. Aquaculture an introduction test. CABI publication, Cambridge, USA, 265 pp.