Bio Economic Features for Aquaponic Systems in Egypt

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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).
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 our 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 m²) with a total area of 240 m² as Integrated Multi-Trophic Aquaculture (IMTA) which includes the following:

- An concrete pond of 40 m³, stocking with low density of Nile tilapia, Oreochromus niloticus (15 fish/ m³).
A concrete pond of 40 m³, stocking with high density with Nile catfish, *Clarias gariepinus* (Burchell, 1822) (5 fish/m³).

- A concrete pond of 40 m³ was used for polyculture of Thin Lipped Grey Mullet, *Liza ramada* (50 fry/m³) and freshwater prawn, *Macrobrachium rosenbergii* (de Man 1879) (84 prawn/m³).

- An earthen pond of 40 m³ was stocking with freshwater clams of *Aspatharia chaiziana* and *Aspatharia maranoi* (Family: Iridinidae) (2.5 kg/m³). An 8 m³ (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:

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SGR = \frac{\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

\[
FCR = \frac{\text{Feed intake (g)}}{\text{weight gain (g)}}
\]

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 m²) with a total area of 378 m² were used for horticulture to grow different vegetable species as hydroponics using aquaculture effluents as nutrients, includes 90 m² 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 m³). 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 m² 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 m³) and catfish (40 m³) ponds to the mullet and freshwater prawn pond (40 m³) and then outflow to the clams pond (40 m³) then to biological
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 m² 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 therefore its correct management can improve the overall fish and plant performance (health and growth). Lethal effects of nitrite (NO\textsubscript{2}), nitrate (NO\textsubscript{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\textsubscript{4}, NO\textsubscript{2}, NO\textsubscript{3} and PO\textsubscript{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-RS monoculture system (Figure 5, Figure 6). The same trend was observed for SGR. The body weight for
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 m³/6 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 m³ 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 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 1.80 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.
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 m²) 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/120m²), 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.
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.

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