Economic feasibility of recirculating aquaculture systems in pangasius farming

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\textbf{ABSTRACT}

This study aims to analyze the economic feasibility of recirculating aquaculture systems (RAS) in pangasius farming in Vietnam. The study uses a capital budgeting approach and accounts for uncertainty in key parameters. Stochastic simulation is used to simulate the economic performance of medium and large farms operating with a traditional system or RAS. Data are obtained through structured surveys and a workshop in the Mekong River Delta. Results show that for large farms, net present value increases from an average of 589,000 USD/ha to 916,000 USD/ha after implementing RAS. Overall, the probability that RAS is a profitable investment is found to be 99\% for both farm sizes. With RAS, the crucial parameters determining profitability are price, yield, costs of fingerling, feed, and initial investment. Findings on the robustness of the economic performance of RAS are useful to support public and private decision making towards increasing the sustainability of pangasius production.

\textbf{KEYWORDS}

Economic feasibility; Monte Carlo simulation; pangasius production; recirculating aquaculture system (RAS)

\section*{Introduction}

Vietnam is the world’s largest producer of pangasius. The European Union (EU) is the main market, accounting for 22.5\% of filet consumption, followed by the United States (20.4\%), and ASEAN (Association of Southeast Asian Nations) countries (6.8\%) (VASEP, 2013). Total production has increased in recent years, from 37,500 tons in 2001 to 1.3 million tons in 2012 (Directorate of Fisheries, 2012). World markets increasingly require seafood products to be produced in a sustainable way. Certification systems aim to guarantee consumers that the product is produced sustainably (Sahota et al., 2009; Bush et al., 2013). To maintain the industry’s export markets, pangasius producers need to ensure that their fish meet sustainability
standards, such as those of the Aquaculture Stewardship Council (ASC) or Global G.A.P. (Belton et al., 2011). Belton et al. (2011) indicate that water use and water quality (i.e., pond effluent management) are key issues in achieving ASC certification.

One of the main sustainability concerns in pangasius production is the impact on the environment, in particular the discharge of organic matter and nutrients, such as nitrogen and phosphorus, to the environment causing eutrophication (Bosma et al., 2009). One way to mitigate these concerns and fulfill the criteria of the ASC standard is to apply water purification at the farm (Anh et al., 2010). Water purification not only has the potential to decrease environmental pollution but can also contribute to a reduction in the occurrence of fish diseases and thus to decreased mortality and lower use of medicines. Recirculating aquaculture systems (RAS) have been introduced to reduce waste discharge and to improve water quality in fish ponds as a response to environmental regulations (Martins et al., 2010; van Rijn, 2013). In order to improve sustainability and enhance ASC certification of Vietnamese pangasius production, RAS has recently been established at a pilot facility at Cai Be station in the Tien Giang province. With ASC certified pangasius products, Vietnamese pangasius exporters expect to become more competitive in export markets (Beukers et al., 2013).

Literature on RAS is limited and generally focuses on technical issues, such as the impact on the environment (Martins et al., 2010; Zhang et al., 2011) and growth of the fish (Webb Jr. et al., 2007; Martins et al., 2009). Economic feasibility analyses have been carried out for some fish species, such as Murray cod in Australia (De Ionno et al., 2006), asp (Aspius Aspius) and ide (Leuciscus idus) in Poland (Kupren et al., 2008), and tilapia in Egypt (Ali, 2012) and Norway (Appiah-Kubi, 2012). Some studies conclude that RAS is an economically viable option (Kupren et al., 2008; Ali, 2012), but others argue that RAS is only feasible for large-scale production facilities (Appiah-Kubi, 2012). Past economic studies on RAS have not addressed pangasius, nor assessed the risks of RAS arising from uncertainties about different factors, such as future prices, yields, and operating expenses. This lack of information may hamper future adoption of RAS by Vietnamese pangasius farmers.

The objective of this article is to analyze the economic feasibility of RAS in pangasius farming in Vietnam. Uncertainty about future prices, yields, operating expenses, and initial investment costs is captured using a Monte Carlo simulation. The investment appraisal is expected to provide useful insights to private (e.g., farmers) and public sectors considering investment in RAS. This article reviews two pangasius farming systems (i.e., traditional system and RAS), the data collection procedure, and the methodology, followed by the presentation of results, discussion and conclusions.
Materials and methods

Description of the two systems

Traditional pangasius farms usually operate one or several 3 to 5 m deep fish pond(s) with a sluice gate, and a feed storage. Stocking densities vary from 18 to 125 fish/m$^{-2}$, depending on the size and availability of fingerlings and the financial capacity of farmers to purchase feedstock (Phan et al., 2009). Nowadays, most pangasius farms use extruded pellets, except for a few small farms in traditional pangasius areas, such as An Giang, where extruded pellets are used together with farm-made feed. Most farms use river water in the fish ponds and discharge waste water directly into the Mekong River. Water exchange is done by pumping or using gravity from the tides.

The application of RAS in pangasius farms requires additional investment in a moving bed bio-filter, filter media, septic tank, and pumps and pipes for water movement and aeration (Figure 1). Only extruded pellets are applicable with RAS.

Data collection

Economic and technical data were gathered in 2013. A survey was conducted to collect data on the traditional system and a workshop was conducted to obtain data on the expected performance of RAS. The workshop was also

Figure 1. Schematic design of pond with RAS facility, based on Nguyen (2013).
used (1) to increase the number of observations on the traditional system for large farms, and (2) to elicit future projections of pangasius prices and yields for both traditional and RAS systems. Surveyed farmers originated from An Giang, Can Tho, and Soc Trang provinces, while participants in the workshop also came from the Dong Thap, Vinh Long and Tra Vinh provinces (Figure 2). Soc Trang and Tra Vinh are new areas (salt water intrusion), while the other provinces are from the main pangasius areas (fresh water).

**Survey**

The survey on the traditional system used a structured questionnaire and was carried out by personal visits in January 2013. Eighty-two farms located in An Giang, Can Tho, and Soc Trang provinces were selected for the survey. These three provinces were selected because pangasius culture in these provinces takes place on relatively small farms. Respondents were selected with the help of local aquaculture officers. Questionnaires were pre-tested a week before the main survey to improve clarity. The questionnaire consisted of three parts addressing 1) initial investment costs; 2) variable costs, fixed costs, and revenues for the most recent production cycle from 2012 until January 2013; and 3) farmers’ socio-economic characteristics.

Figure 2. The sampling location of pangasius farms in the Mekong River Delta.
Initial investment costs included pond construction, sluice gates, waste water treatment (if any), storage houses, and equipment. In case investments were made more than a year ago, replacement costs were assessed. Variable costs covered expenses for pond preparation before stocking (such as costs of lime, salt, and fungicide), fingerling, feed, energy, repair and maintenance, sludge discharge, veterinary services, and labor. Fixed costs consisted of land use, depreciation, and interest paid. If a respondent had multiple ponds, then the respondent chose one of their ponds as a basis for providing information. Production costs and revenues are expressed in USD (applied exchange rate: 1 USD equals 20,000 VND).

Incomplete questionnaires were excluded from the analysis. The survey resulted in 75 complete questionnaires and an additional 14 respondents (large farms) completed the questionnaire during the workshop. A total of 89 questionnaires were available for the data analysis. The average age of the respondents is relatively young, 49 years old, but with considerable experience (about 10 years), and up to 9 years of education (Table 1).

**Workshop**
The workshop was organized near the RAS pilot facility in Cai Be in December 2013. Participants were 29 farmers and 6 experts (Table 1). Small and medium farms were selected from the list of the previous survey, whereas the representatives of large farms were newly invited through companies and cooperatives. Experts were local aquaculture specialists and aquaculture researchers. At the

| Item                                      | Small (<1 ha) | Medium (1–3 ha) | Large (>3 ha) | Total1 | Age (years) | Education (years) | Experience (years) |
|-------------------------------------------|---------------|-----------------|---------------|--------|-------------|-------------------|--------------------|
| **Traditional system**                    |               |                 |               |        |             |                   |                    |
| Farmers                                   |               |                 |               |        |             |                   |                    |
| Main area (freshwater)2                   | 25            | 27              | 2 (+9)        | 54 (+9)| 49 (5)      | 9 (2)             | 12 (2)             |
| New area (salt water intrusion)3          | 9             | 10              | 2 (+5)        | 17 (+5)| 43 (0)      | 9 (1)             | 7 (1)              |
| Total                                     | 34            | 37              | 4 (+14)       | 75 (+14)| 46 (4)      | 9 (2)             | 10 (2)             |
| **RAS**                                   |               |                 |               |        |             |                   |                    |
| Farmers                                   |               |                 |               |        |             |                   |                    |
| Main area (freshwater)                    | 1             | 9               | 9             | 19     | 47 (5)      | 10 (3)            | 13 (1)             |
| New area (salt water intrusion)           | 3             | 2               | 5             | 10     | 45 (6)      | 10 (2)            | 8 (2)              |
| Experts                                   |               |                 |               |        |             |                   |                    |
| Total                                     | 4             | 11              | 14            | 35     | 45 (7)      | 12 (2)            | 11 (5)             |

1Number of respondents from the survey and workshop (in brackets), the classification of farm size is based on the study of Belton and Little (2011); 2Area consists of An Giang, Dong Thap, Can Tho, and Vinh Long provinces; 3Area consists of Soc Trang and Tra Vinh provinces; 4Mean values with standard deviations in brackets.
start of the workshop, participants visited the pilot site where RAS experts explained the design and operation of the system. Afterwards, the large farms (14) were given the opportunity to complete the questionnaire on the traditional system first.

Next, all participants assessed the perceived costs and revenues of RAS using a questionnaire similar to the one used in the survey about the traditional system. Previously filled information on the traditional system was provided as anchor information. Respondents could choose either to implement RAS in a completely new pond or in an existing pond. All farmers chose the latter. The data obtained from the survey and workshop on the traditional system and RAS are summarized in Tables 2 and 3. Outliers, defined as values beyond two standard deviations from the median, were excluded from the analysis (1.5% of the total number of observations). In addition, zero values attributed to sludge discharge costs in RAS were excluded. Some respondents did not perceive these costs as being part of the system.

Initial investment costs per hectare for the traditional system vary widely amongst the categories of farm size, from an average of 64,500 USD for small farms to 83,400 USD for medium farms and 97,500 USD for large farms. Likewise, total variable costs per hectare differ amongst farm sizes, from an average of 553,500 USD for small farms to 587,600 USD for medium farms and 598,100 USD for large farms. This variation is due to different fish stocking densities and varying prices of feed and veterinary services. The main cost items are feed cost (ranging between 84–86% of total variable costs across farm sizes), fingerling cost (7–8%), and veterinary services (2–3%).

Initial investment cost per hectare for ponds with RAS are perceived to be less variable across farm sizes, average costs per hectare are perceived to be 279,500 USD, 333,600 USD, and 334,000 USD for small, medium, and large farms, respectively. Differences likely relate to different quantities of granules filter media, which account for about 80% of total initial investment cost. Total variable costs per hectare are perceived to be higher than for the traditional system, with an average of 644,800 USD, 625,900 USD, and 664,000 USD for small, medium, and large farms respectively. The main cost items are attributed to extruded pellets (ranging between 84–85% across farm sizes), fingerling (9–10%), and veterinary services (1–2%).

The perceived revenues and costs for ponds with RAS are largely consistent with our expectations. In comparison with traditional systems, ponds with RAS allow for higher stocking density (an increase in fingerling costs of 30–34%), less disease outbreaks (reduced veterinary service costs of 39–44%), and lower sludge discharge costs (a decrease of 28–50%). Additionally, the continuous need for electricity or back-up power for
Table 2. Costs and revenues for the traditional system, by farm size (for the most recent production cycle 2012–2013).

| Item                                      | Small farm (<1 ha) $n = 34$ | Medium farm (1–3 ha) $n = 37$ | Large farm (>3 ha) $n = 18$ |
|-------------------------------------------|-----------------------------|--------------------------------|----------------------------|
| i) Initial investment (1,000 USD/ha)      | 64.5 (29.2) 20.4; 120.9     | 83.4 (33.6) 17.6; 147.4        | 97.5 (45.1) 40.9; 173.7    |
| ii) Revenues                              |                             |                                |                            |
| Price (USD/kg)                            | 1.05 (0.06) 0.95; 1.16      | 1.08 (0.07) 0.97; 1.20         | 1.10 (0.06) 1.00; 1.20     |
| Yield (ton/ha/yr)                         | 548.1 (152.4) 222.2; 860.0 | 553.4 (152.4) 333.3; 875.0     | 615.8 (229.2) 322.7; 1000.0|
| Total (1,000 USD/ha/yr)                   | 575.5                      | 597.8                          | 677.4                      |
| iii) Variable costs                       |                             |                                |                            |
| Pond preparation¹                         | 1.5 (0.6) 0.4; 2.9          | 1.1 (0.6) 0.4; 2.5             | 1.3 (1.1) 0.3; 3.4         |
| Fingerling²                               | 44.4 (15.4) 7.1; 81.5       | 44.2 (17.1) 18.6; 76.0         | 44.7 (16.5) 22.5; 83.3     |
| Feed (farm, extruded pellets)             | 501.5 (186.1) 102.9; 785.8  | 508.9 (141.5) 222.5; 766.7     | 519.9 (174.7) 173.9; 877.5 |
| Labor (family, hired)                     | 13.6 (3.7) 6.9; 19.8        | 8.5 (1.8) 5.0; 11.8            | 12.0 (3.3) 6.9; 19.8       |
| Veterinary services                       | 13.6 (8.0) 0.4; 30.0        | 17.8 (5.8) 7.5; 30.8           | 14.9 (6.5) 3.8; 27.7       |
| Sludge discharge                          | 2.1 (1.1) 0.1; 5.0          | 2.0 (1.2) 0.2; 9.1             | 2.2 (1.3) 0.8; 5.0         |
| Energy (electricity, fuel)                | 6.1 (3.3) 0.1; 12.6         | 4.3 (2.7) 0.2; 2.0             | 2.2 (2.0) 0.2; 5.7         |
| Repair and maintenance                    | 0.7 (0.7) 0.1; 2.7          | 0.8 (0.6) 0.2; 2.0             | 0.9 (0.5) 0.3; 1.9         |
| Total variable cost (1,000 USD/ha/yr)     | 553.5                      | 587.6                          | 598.1                      |
| iv) Fixed costs                           |                             |                                |                            |
| Depreciation                              | 5.9 (2.5) 2.9; 12.0         | 6.5 (2.4) 1.2; 9.8             | 7.5 (3.0) 2.7; 11.6        |
| Land use                                  | 1.7 (0.6) 0.8; 3.0          | 1.5 (0.5) 0.6; 2.8             | 1.2 (0.5) 0.7; 2.3         |
| Interest paid                             | 29.0 (4.2) 25.0; 35.0       | 17.3 (10.5) 0.0; 43.9          | 13.4 (9.1) 0.0; 32.9       |
| Total fixed cost (1,000 USD/ha/yr)        | 36.6                       | 25.3                           | 22.1                       |

¹Pond preparation includes costs of lime, salt, and fungicide; ²Fingerling includes costs of fingerling and fingerling treatment.
Table 3. Perceived costs and revenues of pangasius ponds with RAS, by farm size.

| Item                                      | Small farm (<1 ha) n = 4 | Medium farm (1–3 ha) n = 11 | Large farm (>3 ha) n = 14 |
|-------------------------------------------|----------------------------|-------------------------------|----------------------------|
|                                           | Mean (sd)                  | Min; Max                      | Mean (sd)                  | Min; Max                      | Mean (sd)                  | Min; Max                      |
| i) Initial investment (1,000 USD/ha)      |                            |                               |                            |                               |                            |                               |
| Price (USD/kg)                            | 1.09 (0.04)                | 1.05; 1.15                    | 1.09 (0.08)                | 0.98; 1.25                    | 1.13 (0.05)                | 1.05; 1.20                    |
| Yield (ton/ha/yr)                         | 607.7 (239.5)              | 360.0; 890.0                  | 636.9 (121.6)              | 480; 857.1                    | 729.6 (275.3)              | 375.1; 1,142.9                |
| Total (1,000 USD/ha/yr)                   | 662.3                      |                               | 694.2                      |                               | 824.4                       |                               |
| ii) Revenues                              |                            |                               |                            |                               |                            |                               |
| Pond preparation¹                         | 1.2 (0.1)                  | 1.1; 1.3                      | 1.1 (0.7)                  | 0.1; 2.1                      | 1.3 (1.2)                  | 0.1; 3.5                      |
| Fingerling²                               | 61.1 (19.6)                | 40.1; 81.5                    | 67.2 (13.5)                | 45.1; 95.4                    | 69.6 (17.5)                | 40.2; 97.3                    |
| Feed (extruded pellets)                   | 549.6 (106)                | 423.7; 696.3                  | 524.1 (63.7)               | 410.4; 643.3                  | 560.9 (124.5)              | 375.0; 769.9                  |
| Labor (family, hired)                     | 8.1 (2.1)                  | 6.2; 11.3                     | 7.9 (2.5)                  | 4.7; 13.1                     | 8.2 (2.1)                  | 5.9; 13.2                     |
| Veterinary services                       | 8.2 (0.9)                  | 7.1; 9.3                      | 10.6 (4.2)                 | 4.9; 17.1                     | 8.4 (2.7)                  | 5.0; 14.1                     |
| Sludge discharge                          | 1.5 (0.9)                  | 0.4; 2.7                      | 1.0 (0.3)                  | 0.6; 1.4                      | 1.1 (0.7)                  | 0.4; 2.3                      |
| Energy (electricity, fuel)                | 11.8 (3.8)                 | 6.4; 17.1                     | 11.4 (4.0)                 | 4.5; 20.0                     | 12.7 (5.8)                 | 5.6; 27.0                     |
| Repair and maintenance                    | 3.3 (1.0)                  | 2.1; 4.9                      | 2.6 (1.0)                  | 1.0; 4.3                      | 1.8 (1.0)                  | 0.7; 3.8                      |
| Total variable cost (1,000 USD/ha/yr)     | 644.8                      |                               | 625.9                      |                               | 664.0                       |                               |
| iv) Fixed costs                           |                            |                               |                            |                               |                            |                               |
| Depreciation                              | 19.6 (0.2)                 | 16.7; 23.8                    | 23.2 (4.7)                 | 11.7; 38.0                    | 25.0 (3.4)                 | 13.2; 40.0                    |
| Land use                                  | 1.0 (0.0)                  | 0.8; 0.9                      | 1.4 (0.5)                  | 0.7; 2.4                      | 1.1 (0.4)                  | 0.7; 2.0                      |
| Interest paid                              | 39.0 (4.5)                 | 35.0; 46.0                    | 26.5 (7.1)                 | 16.9; 42.9                    | 25.3 (13.6)                | 0.0; 52.9                     |
| Total fixed cost (1,000 USD/ha/yr)        | 59.6                       |                               | 51.1                       |                               | 51.4                        |                               |

¹Pond preparation includes costs of lime, salt, and fungicide; ²Fingerling includes costs of fingerling, and fingerling treatment.
circulation increases energy costs (an increase of 48–80%). Values for interest paid are lower than we expected, probably because farmers believe that they will be eligible for low-interest loan programs offered by the government for investments in aquaculture innovations.

In the next phase of the workshop, participants projected pangasius prices and yields for a period of 15 years (2013–2028), for both the traditional system and RAS. The 15-year period was chosen to capture the assumed lifetime of ponds. Each farmer and expert projected prices and yields by filling in figures in the questionnaire (similar to Figure 3). A final estimate of prices and yields per year was obtained in two steps. First, we calculated the mean values of all respondents’ projections for four years (2013, 2018, 2023, and 2028) and drew a trend line through these four values. Second, a discussion was initiated among the respondents until 95% reached a consensus about the trend of the presented line. The agreement level is in line with the recommendation of Kaner (2014), i.e., at least 80% agreement is acceptable to reflect consensus. Respondents, who did not totally agree with the price trend for RAS, stated that “there has been no explicit price premium offered by processing companies for Global G.A.P certified pangasius products.” Hence, they believe that the price premium for ASC certified pangasius products is also not guaranteed.

![Figure 3. Projection (2013–2028) of prices and yields for the traditional pangasius system and RAS.](image-url)
The projected consensus values for yields and prices for RAS and traditional systems are shown in Figure 3. Values for RAS are higher than those of the traditional system. Respondents expect a price premium of 0.03 USD per kilogram fish per year with RAS compared to the traditional system and the annual yields with RAS are expected to be 1.3 times higher.

**Net present value (NPV) calculation**

Capital budgeting is an appropriate approach for assessing and comparing the economic feasibility of the two pangasius farming systems. The net present value (NPV) method was used in this study because it considers cash inflows and outflows over the whole lifetime of the investment. An investment’s NPV is defined according to the following equation (Barry & Ellinger, 2010; Kay et al., 2012):

\[
NPV = -INV + \sum_{t=1}^{T} \frac{NCF_t}{(1 + i)^t} + \frac{V_T}{(1 + i)^T}
\]

where \(INV\) is the initial investment, \(NCF\) is the annual net cash flow, which equals annual cash inflow (annual revenues) minus annual operating cash expenses (sum of annual variable costs and annual fixed costs excluding annual depreciation and interest), \(V\) is terminal value, \(i\) is the discount rate, and \(T\) is the lifetime of the investment.

The lifetime of the investment in a pond was assumed to be 15 years for both the traditional system and the RAS. A salvage value of 0 USD was used for all equipment (including the pond) at the end of the investment horizon. The monthly salary for hired labor in the aquaculture sector was used as the opportunity cost to quantify the expense of family labor. All expenses were assumed to increase by 2% per year due to inflation, based on the producer price indexes for agricultural, forestry, and fishery products in the fourth quarter of 2012 (General Statistics Office of Vietnam, 2012). Price projections (Figure 3) were assumed to include a similar inflation percentage. The discount rate was 20%, incorporating 8% opportunity cost of capital (Agribank, 2014), a risk premium of 10% (De Ionno et al., 2006), and inflation of 2%. Straight line depreciation was assumed for all equipment and storage houses.

**Monte Carlo simulation**

**Simulation model**

Investment cost, pangasius yields, market prices, and the operating expenses are uncertain. To assess the risk associated with these uncertain variables, a Monte Carlo simulation was developed. The outcomes of the simulation
provide information about the likelihood that investing in RAS versus the traditional system is economically viable. In addition, the simulation results show whether a range \((a, b)\) of NPV likely falls within a confidence interval (Gebrezgabher et al., 2012), such that:

\[
\int_a^b f(NPV_1 \ldots NPV_k) dNPV = \text{probability}(a \leq NPV \leq b)
\]

where \(f\) denotes the probability function based on the NPV input data. The Oracle\textsuperscript{\textregistered} Crystal Ball software was used to simulate NPV and profit using 1,000 iterations (Engle, 2010). The stochastic input variables were initial investment cost, annual yields, annual prices, and annual expenses, i.e., costs of fingerling, feed, labor, veterinary services, land use, sludge discharge, energy, repair and maintenance, and annual interest.

RAS is costly and thus adoption is more likely by medium and large farms. Simulations were carried out for these farms (not for small farms). Normal distributions were used to describe uncertain annual prices and annual yields of pangasius farming. Initial investment cost and annual operating expenses were specified as triangular distributions. Similar distributions were used by Valderrama and Engle (2001) for shrimp farming, and Gebrezgabher et al. (2012) for biogas systems.

The parameterization of the distributions is shown in Tables 2 and 3. For normal distributions we used the mean and standard deviation (assumed to be constant over the investment horizon of 15 years). For triangular distributions, we used the minimum, maximum, and most likely values, which were derived from the minimum, maximum, and mean values, respectively (Vose, 2008). The 2014–2028 price and yield projections for each farm size were derived by using the relative changes over time (for all farms, as shown in Figure 3) with the price and yield values for the starting year for each farm size (Tables 2 and 3). Correlations were applied between feed costs and yields \((r = 0.9)\), and between fingerling costs and yields \((r = 0.7)\), the latter only for medium farms. The correlations \((P \leq 0.05)\) were estimated from data from the survey of farms with the traditional system (Table 2) and were assumed to be similar for RAS.

**Sensitivity analysis**

To obtain insight in the stochastic input variables in the simulation that have an important impact on the NPV, the Spearman rank correlation coefficients between NPV and the variables were computed. The higher the value of the Spearman rank correlation coefficient, the higher the correlation between a variable and the NPV, and the stronger the association between them.
Table 4. Mean economic performance of the traditional system and RAS by farm size, simulated results from 1000 iterations.

| Item                                      | Traditional | RAS  |
|-------------------------------------------|-------------|------|
| **i) Initial investment (1,000 USD/ha)**  |             |      |
| Medium farm                               | 82.0        | 326.0|
| Large farm                                | 97.2        | 338.0|
| **ii) Revenues**                          |             |      |
| Price (USD/kg)                            | 1.22        | 1.32 |
| Yield (ton/ha/yr)                         | 658.1       | 730.0|
| Total (1,000 USD/ha/yr)                   | 802.9       | 963.6|
| **iii) Variable costs**                   |             |      |
| Pond preparation                          | 1.3         | 1.2  |
| Fingerling                                | 52.1        | 60.0 |
| Feed (farm, extruded pellets)             | 592.0       | 604.3|
| Labor (family, hired)                     | 10.2        | 6.1  |
| Veterinary services                       | 21.1        | 12.1 |
| Sludge discharge                          | 2.3         | 1.2  |
| Energy (electricity, fuel)                | 4.9         | 13.0 |
| Repair and maintenance                    | 0.8         | 2.9  |
| Total (1,000 USD/ha/yr)                   | 684.7       | 700.8|
| **iv) Fixed costs**                       |             |      |
| Depreciation                              | 5.4         | 17.5 |
| Land use                                  | 1.7         | 1.6  |
| Interest paid                             | 20.2        | 22.4 |
| Total (1,000 USD/ha/yr)                   | 27.3        | 41.5 |
| Mean profit (1,000 USD/ha/yr)             | 97          | 228  |
| Mean NPV (1,000 USD/ha)                   | 262         | 539  |

Results

Economic performance of RAS

Table 4 presents the mean economic performance of the traditional system and RAS. The average annual profit for the traditional system ranges from 97,000 USD/ha (medium farms) to 177,000 USD/ha (large farms). After implementing RAS, the average annual profit is expected to increase to 228,000 USD/ha and 306,000 USD/ha for medium and large farms. In addition, when shifting from the traditional system to RAS, the mean NPV/
ha increases from 262,000 USD to 539,000 USD for medium farms, and from 589,000 USD to 916,000 USD for large farms.

In addition to average performance, the robustness of the outcomes is also relevant for decision makers. Table 5 shows the variation in profitability and NPV for each farm size. Results illustrate that there is more variation in the performance of the RAS, as shown by the increased standard deviation of profitability and NPV. At the same time, however, the performance of RAS is generally better, both for annual profitability and NPV.

**Sensitivity analysis**

Table 6 shows the highest Spearman rank correlation coefficients between NPV and the stochastic input variables. Associations are generally stronger for RAS than for the traditional system. Outcomes show that an increase in initial investment cost significantly lowers the NPV in the case of RAS, i.e., $r = −0.38$ and $−0.15$ for medium and large farms, respectively. The highest association is found for yields, especially with RAS in large farms ($r = 0.90$). The association between NPV and feed costs is highest for large farms as well ($r = 0.77$).

**Discussion and conclusions**

This study shows that farmers are generally positive about the economic performance of RAS systems. Based on the perceptions of farmers and experts, the NPV of investment substantially increases with the adoption of RAS, for both medium and large farms. Crucial factors leading to the improved economic performance are improved yields and prices, along with less disease costs. The increase in profitability due to RAS found in this study is in line with studies by Kupren et al. (2008) on asp (Aspius Aspius) production, and Ali (2012) and Appiah-Kubi (2012) on tilapia production, although the latter only found positive effects for large farms.

This study assesses the economic feasibility of an innovation based on the perception of farmers and experts. Our arguments for the validity of this approach are as follows. First, this approach is currently the only possible...
approach for assessing RAS in pangasius production in Vietnam, as this system is currently only used in a pilot project. Hence, farm-level economic information on yields, prices and costs for pangasius cultivation with RAS are not available. Second, respondents were well-informed before they started completing the questionnaires.

The workshop was organized at the pilot facility and the system was elaborately shown and explained by the aquaculture expert responsible for running the pilot facility prior to completion of the questionnaire. Third, the elicited values at the workshop are generally in line with our expectations, e.g., with regard to increased stocking densities and costs of energy. Fourth, the number of outliers was found to be fairly limited. With regard to the elicited data for the traditional system, positive net farm incomes were also found by Kam et al. (2012), although their scenarios predicted negative results after 2015 (coastal zones) and 2018 (inland pangasius farms).

Outcomes of this study can be used by policymakers (such as the Ministry of Agriculture and Rural Development of Vietnam) and private sectors (retailers and farmers) to assess the robustness of the economic performance of RAS for Vietnamese pangasius farms. The key variables influencing the profitability of RAS provide a basis for policy recommendations. For instance, to help farmers cope with the relatively high initial investment costs for setting up the RAS system, governments could provide free-interest loan programs to pangasius farmers who are willing to implement RAS on their farms. Furthermore, farmers who implement RAS expect a price premium for their product and higher yield to partially compensate for the high investments. Private sectors (retailers) could guarantee a price premium for ASC certified pangasius products.

Acknowledgments

The authors acknowledge the assistance of Mr. Nguyen Nhut, PhD candidate in Aquaculture and Fisheries Group, Wageningen University, for technical explanations on RAS during the workshop. Farmers and experts who participated in the survey and workshop are gratefully acknowledged.

Funding

This research was financed under the SUPA (improving waste management for pangasius culture in the Mekong Delta of Vietnam) project, as part of the bilateral Vietnamese-Netherlands Public Private Partnership between the Vietnamese Ministry of Agriculture and Rural Development (MARD) and the Ministry of Economic Affairs from the Netherlands.

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