BIOECONOMIC ANALYSIS OF RATION SIZE IN NILE TILAPIA FEEDING: AN EXAMPLE OF YUCATAN, MEXICO

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ABSTRACT

Nile tilapia has been cultivated in intensive systems in Yucatan, Mexico, during the first years of this century. Nevertheless, its adoption faces technical (related to the use of commercial feed) and marketing problems (fixed price of $2.14/Kg), which are analyzed in this paper. To do this, a bioeconomic model of Nile tilapia cultivation was estimated for four different ration sizes: 50%, 80% and 100% of the ration recommended by feed suppliers, and the satiety ration. The model was simulated for different scenarios, including three fixed harvest sizes and two market conditions (fixed and size-dependent price). Independently to price schedules, the optimum ration size was positively dependent on harvest size. Moreover, the highest profits were achieved with a harvest size of 400 g for the case of size-dependent price, which is reduced to 300 g for a fixed fish price. All optimal ration sizes were located with values below ration recommended by feed suppliers (0.84). The application of these results could increase producer income and improve input efficiency.

Keywords: Ration size, Nile tilapia, fixed price

INTRODUCTION

Commercial aquaculture involves diverse internal and external factors that influence the economy of production; particularly aspects related to growth and feed efficiency, since the costs of feeding can represent 40-50% of the total operation costs [1]. In order to mitigate this cost, balanced feed manufacturers offer feeding tables that indicate the food ration according to fish size (% body weight) and water temperature. However, in some cases the producers only take into account the observation of surface feeding, they do not use said tables, offering rations to satiety to the fish without knowing the effect this has on the feeding cost and the generation of nitrogenous wastes [2, 3, 4].

On the other hand, producers face external factors that they cannot control: adverse market conditions, variation in demand and increases in input costs. In Yucatan, Mexico, the intensive production of tilapia is beginning to be an investment option in rural areas. However, the lack of knowledge and commercial organization of the producers does not allow them to obtain competitive prices for their product, making them dependent on wholesale buyers, who set a fixed price for the tilapia (300 a 500 g) without giving additional value to large sizes. Similar conditions have been observed in rural areas of China, where the profit margin in each link of the commercial chain is 10 to 20 %, with the producer being the person that earns the least [5], since the base farm-gate price of tilapia can fluctuate by -17.28% a 8.64 % [6]. Other aspects such as the lack of sanitation and infrastructure suitable for commercialization also limit the ability of the producers to negotiate appropriate prices for their products [7].

Consequently, the rural producers of Yucatán face problems that have a considerable impact on the expected profits. The specific conditions of the market make it necessary to apply more efficient production systems that respond to these situations. The appropriate selection of the ration size throughout the cultivation cycle is one of the production pathways of greatest impact in the production efficiency of the fish farm, which is reflected in the production costs. On the other hand, finding an optimum cultivation ration implies both economic and environmental benefits, since in aquaculture any feeding inefficiency can, in addition to increasing the production costs, increase the negative externalities related to the use of inputs [8, 9]. A farm that operates inefficiently will use more inputs than necessary to generate a determined production quantity

In a situation where prices are independent of size, the optimum choice of ration size combined with the final harvest size can represent an important saving for the producers, which enables them to survive and/or obtain better yields. However, in the literature few studies exist that analyse the optimum ration size for different harvest sizes. In this respect, [10] studied different ration sizes in fingerlings of Eurasian perch (*Perca fluviatilis*) for fishes of 0.22, 0.73, 1.56 and 18.9 g, by means of a graphic analysis, finding optimum rations for each of them; 0.42, 0.76, 0.70 and 0.59 respectively. However, the previous study did not include an economic analysis, in addition to which it was carried out for harvest sizes well below that which is commercial.

In this sense, bioeconomic models are a useful tool for studying the interaction of biological, environmental, economic and market components. A number of bioeconomic models have been focused on determining the optimum harvest time and size, based on different cost and price scenarios, assuming that the biggest fish present higher market prices [11, 12, 13]. The study by [14] relates, on a theoretical level, the optimum harvest time with optimum feeding trajectories, which has been extended in the studies of [15, 16, 17].

In this context, in the present study the optimum ration sizes and market sizes for the tilapia market conditions in Yucatán, México were estimated. In order to achieve this, a bioeconomic model based on technical-biological experimental data and market data was constructed. The results offer management strategies (ration and harvest sizes) to the producers facing the adversities that the market imposes upon them.

MATERIALS AND METHODS

Experimental outline

An experiment was carried out from May to November of 2006, where the growth and feeding efficiency of juvenile tilapia, fed with balanced commercial feed, were studied. Male fish were used with an average starting weight of 14.23 ± 0.23 g, provided by the aquaculture lab of CINVESTAV. The feed was supplied based on the feeding tables, which was considered as the control (100%), and three treatments: satiety (>100%), 80% and 50% in regards to the recommended ration. The feed was divided into four daily portions and was offered manually, distributing it in a uniform manner to avoid spatial competition.

The experimental system consisted of eight indoor circular fibreglass tanks, with a volume of 0.75 m^3 of useful capacity per tank. The experiment was performed in duplicate for each treatment. The tanks were randomly distributed and the stocking density was 44.0 fish/m^3. To avoid the accumulation of nitrogenous wastes, the maintenance of the tanks consisted of siphoning off the faeces, daily replacement of water (25%), total replacement of water once a week and general cleaning every 14 days in order to remove the biota that had settled on the walls of the tanks. The amount of feed consumed daily according to each treatment was recorded.

Bioeconomic model

A standardization of the ration was performed, in a range of 0 (starvation) to 1 (satiety) according to: 1) the estimation of the ration size (% body weight) for each treatment, 2) the ration size at satiety is the maximum ration consumed by the fish by means of experimentation, and 3) divide the ration size of all the treatments between the maximum experimental ration. The latter is the equivalent to standardize each ration with respect to the satiety ration.

The biological sub-model

To represent fish growth $(\dot{w} = g(w))$ in each treatment, a von Bertalanffy-type equation was chosen, which describes the daily growth rate of the organisms according to:

$$g(w) = \eta w^{2/3} - \kappa w, \qquad \text{(Eq. 1)}$$

where w is the weight of the fish, η and κ are anabolism and catabolism coefficients respectively [18]. Considering that the amount of feed is a factor that influences the anabolic component of growth, in equation 2 a ration function has been included as a multiplicative factor, assuming an optimum temperature during growth. The parameterization was performed with the Statistica software using the standardized ration size of each treatment and the growth rate associated with weight as seed values:

$$g(w,r) = \eta f(r) w^{2/3} - \kappa w, \qquad \text{(Eq. 2)}$$

where $f(r)$ is the ration function. The final function described here is written:

$$f(r) = r^{\varphi} e^{\varphi(1-r)}, \qquad \text{(Eq. 3)}$$

where r is the size of the standardized ration, $0<r<1$, y φ is a parameter. The weight of the organisms in time t, $w(t)$, was obtained from the iterative integration (Euler method with a time step of one day) of the instantaneous growth rate and the weight observed earlier.

The management sub-model

The biomass of the system ($B(t)$) during cultivation was estimated according to:

$$B(t) = w(t)N(t), \qquad \text{(Eq. 4)}$$

where N(t) is the number of fish at time t (N_0 is the number of fish initially stocked):

$$\dot{N}(t) = -(1 - S_V(t))N(t); \quad N(0) = N_0. \qquad \text{(Eq. 5)}$$

Where $S_V(t)$ is the daily survival rate (%/day) at time t. In order to simulate the feed consumption for each ration, different functions were tested (quadratic, exponential, logarithmic, etc.) according to the FCR observed. Said function also considered the values of the feeding tables, determining that the best fit to the data was obtained by the expression:

$$f(t,r) = \left[\Omega + r(\phi_A w(t)^{\phi_B}) + (\phi_C)\right]B(t). \qquad \text{(Eq. 6)}$$

This empirical expression represents the amount of feed supplied in each treatment in terms of % body weight, Φ_A, Φ_B, y Φ_C are parameters and Ω is an adjustment factor.

$$\Omega = \ell_A r^{\ell_B} + \ell_C r + \ell_D, \qquad \text{(Eq. 7)}$$

where ℓ_A, ℓ_B, ℓ_C, ℓ_D are parameters.

The economic sub-model

The economic sub-model included the variables with the greatest impact on the economic results; the costs and prices are in US Dollars ($). The Fixed Costs ($C_F$) were based on the depreciation of the tanks, aeration equipment and water pump and the interests on the investment. The time-variable costs of each ration scenario ($C_V(t,r)$) were generated from the start of the cultivation until the harvest:

$$C_V(t,r) = C_L(t) + C_{ENER}(t,r) + C_{BF}(t,r) + C_F N_0, \qquad \text{(Eq. 8)}$$

where C_L is the cost of labor, C_{ENER} is the energy cost, C_{BF} is the cost of the balanced feed and C_F is the cost of the juvenile (number initially stocked). The energy cost was modelled with information provided by farms that have experience using feeding to satiety regimes, according to:

$$C_{ENER} = B(t)E(r), \qquad \text{(Eq. 9)}$$

where $E(r)$ is the cost of maintaining a Kg of tilapia per day (24h) (pumping of water and aeration), which depends on the ration supplied. The following expression has been estimated for this dependency:

$$E(r) = cr^2 + dr - h, \qquad \text{(Eq. 10)}$$

where c, d and h are parameters. The total cost is the result of the sum of the variable costs and the fixed cost.

Total income is obtained from the product of the biomass at the time of harvesting by the sale price of tilapia. In the present study two price conditions were analyzed, a fixed price ($ 2.14/Kg), independent of the harvest size (FP) and a size-dependent price, dependent on the harvest size (SDP), which was calculated according to:

$$p(w(t)) = \rho(1 - e^{(\sigma * w)}), \qquad \text{(Eq. 11)}$$

where ρ, is the maximum price of Nile tilapia per Kg and σ is a constant.

The system model and the assumptions for bioeconomic analysis

The cultivation system analyzed here includes only one fattening tank of 16 m in diameter and 1.2 m in height (240 m^3) with an aeration system. The number of juvenile stocked was 11,000 per tank, whose initial size was approximately 12-15 g. The fattening cycle is estimated to be 4-6 months, time in which the organisms reach sizes of 200-500 g. The parameters of the management and economic sub-model were obtained from statistical analysis (Table 1).

Table I. Parameters used in the intensive management sub-model

Parameters	Units	Amount
Feeding parameters		
Φ_A		0.14288
Φ_B		-0.37323
Φ_C		-0.00092
Correction factor Ω		
ℓ_A		0.0051
ℓ_B		0.0008
ℓ_C		0.0048

The assumptions of the bioeconomic model: tank capacity, stocking density and weight, costs, inputs and sale prices of tilapia, were based on information from commercial farms and the market in Yucatán, Mexico (Table II). Labor was calculated based on the minimum daily salary ($4.34/day) in proportion to the time an employee would dedicate to jobs on the farm. The costs of the balanced feed and juvenile were established based on the market current price in 2010, in addition to which a discount rate *i* according to the Mexican Federal Treasury Certificates (CETES) at 28 days was considered.

Table II. Assumptions used in the bioeconomic model

Concept	Units	Amount
Tank capacity	m^3	241.27
Stocking density	fish/m^3	45.6
Initial weight	g	14
Survival rate (S)	%/day	99.9730
Variable Costs:		
Balanced feed (C_{BF})	$/Kg	0.73
Labor (C_L)	$/day/tank	1.44
Cost of juvenile	$/juvenile	0.08
Fixed costs	$	415.38
Fixed price (FP)	$/Kg	2.14
Annual discount rate (*i*)	%	7.3
Energy function		
c		0.366
d		0.236
h		0.057
Parameters of the price of tilapia		
Function of size-dependent price		
Maximum farm-gate price (ρ)	$/Kg	2.54
σ		0.0080

This study analyzes the case of only one cultivation cycle, considering an optimum cultivation temperature of 29 ºC. The problem for the producer is finding the ration size and harvest time that maximize the profits π according to a specific harvest size, expressed as:

$$\begin{aligned} &\underset{r,t_h}{Maximize}\ \pi = e^{-it_h} p(w_h) w_h N(t_h) - C_F - \int_0^{t_h} e^{-it} C_V(t,r)dt, \\ &s.t. \quad \int_0^{t_h} g(w(t),r)dt = w_h. \end{aligned} \tag{P}$$

where w_h is the harvest size (200, 300, y 400 g).

RESULTS

Experimental results

The results of the experiment are shown in table III. The experiment lasted 182 days; in the start, the treatments showed no significant differences in average weight, since fish of the same size were selected to avoid biases, the water replacements were constant and the water temperature was kept stable.

Table III. Results of growth, FCR and survival, after 182 experimental days

	Units	50% (0.42)	80% (0.67)	100% (0.84)	Satiety (1)
Inicial weight	g	14.44±1.2[a]	14.53± 1.1[a]	14.10± 1.3[a]	14.56±1.2[a]
Final weight	g	206.85±27.2[a]	292.16±42.4[ab]	314.40±65.5[b]	334.10±70.7[b]
Weight gained	g	192.41±26.0[a]	277.63±41.3[ab]	300.22±64.2[b]	319.54±69.6[b]
GR	g/day	1.13±0.0[a]	1.52±0.0[ab]	1.66±0.0[b]	1.75±0.0[b]
FCR	g BF:1 g Wg	1.34± 0.0[a]	1.59±0.2[b]	1.75±0.0[c]	1.92±0.1[d]
Survival	%	91.94±2.3[a]	95.26±2.4[a]	93.51± 3.2[a]	93.55± 4.6[a]

GR = Growth rate, FCR = Food conversion rate

With regards to survival, even though the treatment with the ration of 50% presented the lowest percentage, no significant differences were found between treatment (p>0.05), keeping above 90%. The values of the final weight, weight gained and GR registered for the treatment with the ration of 50% presented significant differences with respect to the ration of 100% and satiety. The ration of 80% did not report significant differences with any treatment (p>0.05). The results of the FCR showed differences between all the treatments, which represent a significant increase in this parameter when the ration size increases.

The standardization was located in 0.43 and 1, the smallest and biggest ration tested experimentally (50% and satiety) respectively, with 0.84 being the value of the recommended ration (100%). In studies with the gilt-head seabream [19, 17] a standardized ration of 0.80 was used, the equivalent to the ration recommended by the feeding tables, which is close to that estimated here (0.84). Estimation of the von Bertalanffy equation parameters produced significant values (Table IV). The model was validated through the estimation of the parametric statistics, mean square error and Theil's *U*, obtaining satisfactory results.

Table IV. Parameters of von Bertalanffy-type equation

Parameters	Amount	Significance
η	0.1575	$p<0.05$
κ	0.0169	$p<0.05$
φ	0.4937	$p<0.05$

Optimum ration for different harvest sizes

The problem optimum (P) was calculated through the simulation of the bioeconomic model for three final harvest sizes w_h in the two price scenarios described above (SDP and FP). The FP scenario (price independent of size) represents the current situation of the intensive tilapia producers in Yucatán.

The simulation indicates that for harvest sizes of 200 and 300 g, the optimum ration size is the same for both price scenarios. However, for harvest sizes equal to 400 g, the optimum ration for FP is lower than that for SDP (Figure 1). Nevertheless, when comparing the economic yields of the harvest sizes and their respective optimum rations, it was observed that the harvest size that generated greater profits depended on the market conditions. Considering the FP scenario (current situation), it would prove more convenient to harvest at intermediate sizes, since the profits are greater when harvesting at a size of 300 g compared to 400 g. With regards to the SDP scenario, the greatest profit is reached at a 400 g, since the market pays a better price for large sizes. Harvesting at sizes above the optimum harvest size can cause a decrease in the expected profits, regardless of the market conditions.

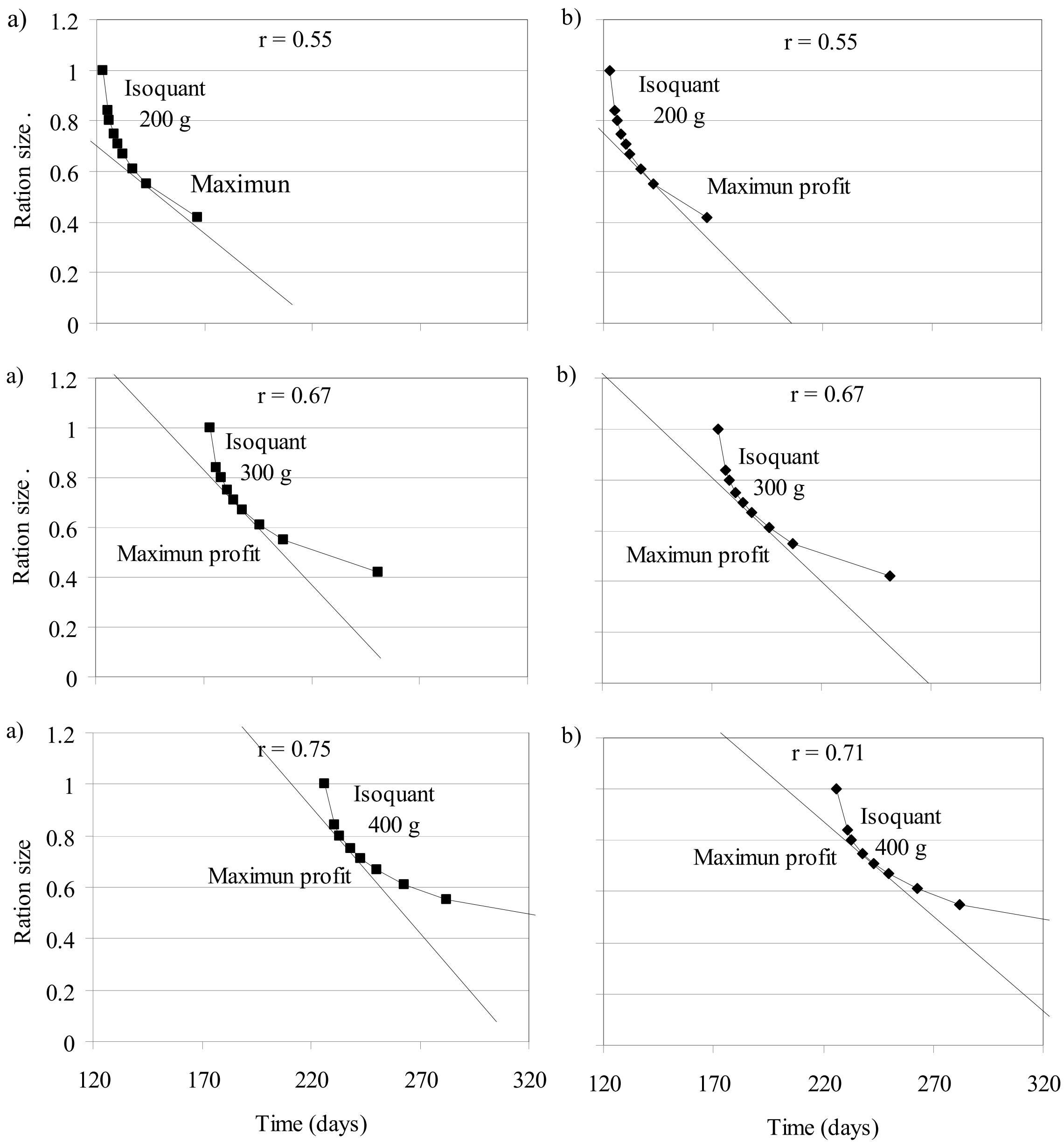

Figure 1. Ration sizes that maximize the profits for different harvest sizes, a) size-dependent price scenario (SDP) and b) fixed price scenario (FP).

Figure 2 shows the optimum profits obtained as function of the final harvest size in both price scenarios. In the current situation (FP), it would be more convenient to harvest at a size of 300 g, obtained in 188 days with an optimum ration of 0.67. With regards to the SDP scenario, the greatest profit is reached at a harvest size of 400 g, with an optimum ration size of 0.75, obtained in 238 days. Both optimum rations are below the ration recommended by the feeding tables (0.84).

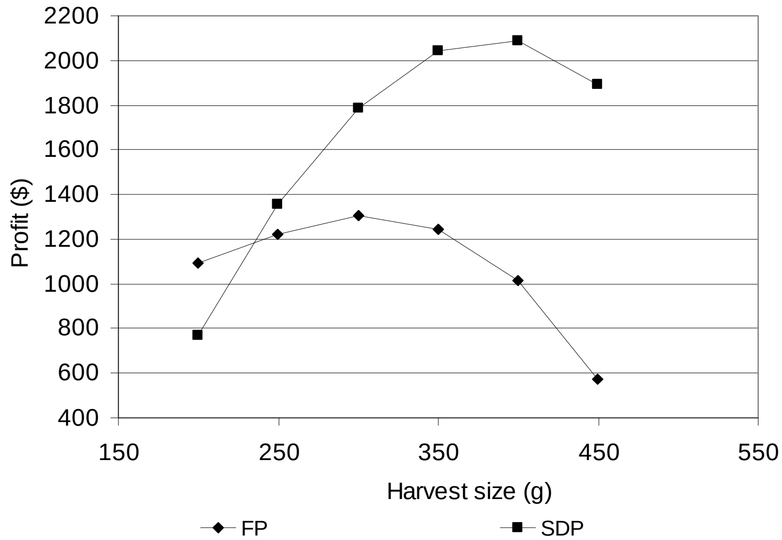

Figure 2. Profits generated for different harvest sizes in both price scenarios (SDP and FP).

The results and recommendations of this study may help the producers of the Yucatan to face the market problem, reducing the economic adversity implied by the fixed price of \$2.14/Kg. The methodology followed in the present study can be applied to the study of tilapia cultivation and the that of other species in regions different to Yucatan, Mexico, provided that the possible existence of variations in the results of growth, feeding conversion and optimum ration are taken into account, due to aspects related to the species, genetic line, environmental conditions, type of feed, cultivation density, etc.

CONCLUSIONS

The study of the optimum ration is a subject of extreme importance in the cultivation of species, since the chosen ration should balance an excellent GR with a low FCR, guaranteeing rapid growth of the fish. In this sense, the bioeconomic model enabled the optimum rations for different harvest sizes of tilapia (200-400 g) to be estimated, according to different conditions of the market in Yucatán, México. In this way, the results offer management alternatives so that tilapia producers in this region face the current situation characterised by a low negotiation power when facing the distributors. The recommendation is that the ration size be adjusted to below the ration indicated by the feeding table, and above all, avoid operating with satiety rations, since this latter ration carries with it considerable economic losses. This study represents an approach to the problem of optimum management of the inputs for producers in rural zones of regions of low income, which could be complemented by various pathways. One of these is a market study directed towards finding out the local market segmentation for tilapia and its relative prices.

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