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AVALIAÇÃO DOS IMPACTOS AMBIENTAIS DA TILÁPIA CULTIVADA EM SISTEMA SEMI-INTENSIVO

Assessment of environmental impacts of the semi-intensive tilapia culture system

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Resumo

O principal objetivo do presente estudo é avaliar as características físicas, químicas e bacteriológicas dos efluentes contínuos e da despesca de peixes como a tilápia (Oreochromis niloticus), analisar os possíveis impactos das descargas de águas residuais e propor alternativas para minimizar os seus efeitos. As amostras foram coletadas entre abril e outubro, abrangendo assim todo o ciclo de desenvolvimento de tilápia. A demanda de oxigênio dissolvido é a principal causa de problemas ambientais, mas o índice de eutrofização é baixo, apesar de apresentar consideráveis níveis de fósforo total em comparação com os padrões legais estabelecidos pela Resolução 357/05 do Conselho Nacional do Meio Ambiente do Brasil (CONAMA). O índice de pressão ambiental elevou-se a 2,47, o que reforça a necessidade de medidas que possam minimizar esse impacto. A utilização de águas residuais na irrigação é a melhor alternativa, resultando em uso racional da água, menores taxas de utilização de fertilizantes e redução da poluição hídrica.

Palavras-chave: *impacto de águas residuais, piscicultura, tilápia.*

Abstract

The main objective of the present study is to assess the physical, chemical and bacteriological characteristics of continuous wastewater and of fish harvesting in tilapia (Oreochromis niloticus) farming, considering the possible effects of wastewater discharges and alternatives to minimize their effects. The samples were collected between April and October, thus spanning the whole developmental cycle of tilapia. The dissolved oxygen demand is the major cause of environmental problems, but the eutrophication index is low despite considerable total phosphorus levels compared to the legal standards established by Resolution 357/05 of the Brazilian National Environmental Council (CONAMA). The environmental pressure index amounted to 2.47, which underscores the necessity for measures that can minimize this impact. The use of wastewaters in irrigation is the best alternative, resulting in rational water use, lower fertilizer utilization rates and reduction of water pollution.

Keywords: *impact of wastewaters, fish farming, tilapia.*

1 Introdução

The expansion of aquaculture in the last few decades in the wake of technological advances, diversification, production and intensification of farming has turned it into an important economic activity in several countries (IBRAHIM & EL NAGGAR 2010; CARVALHO et al., 2010).

In fish farming, some consequences of this process are quite evident as the boost in demand for consumer goods has had implications for different production sectors, often causing deleterious effects on the environment and natural resources. This is the case of wastewaters generated from fish farming, which are discharged virtually always without any pretreatment, bringing negative consequences for the environment. During cultivation, pond wastewaters may not have a high concentration of nutrients, but most of the organic matter input, chiefly in the form of feed and fertilization, is not metabolized by animals and/or is not consumed, thus accumulating at the pond bottom and increasing the concentrations of inorganic compounds derived from nitrogen, phosphorus, and organic matter, in addition to other potential pollutants that can be released into the environment during harvesting (ARVANITOYANNIS & KASSAVETI, 2008; AZAZA et al., 2009; AUBIN et al., 2009; CONTE et al., 2008; LIN et al., 2010).

The impacts of these discharges into the environment should be minimized and wastewater reuse is an evident trend aimed at reducing the problem and adding value to the residue.

In terms of water usage, aquaculture is considered a waste-producing activity as wastewaters are discharged into the receiving body (CONAMA's resolution 357/05 and CONSEMA's resolution 128/06) (Brasil, 2005; Brasil, 2006). The environmental laws governing these activities are comparable mainly to those on marine environments adopted in other countries, with restrictions on organic residues produced by these activities (BACKMAN et al., 2009).

Given the issues outlined above, the aims of the present study are to monitor the tilapia culture pond and to assess the physical, chemical and bacteriological characteristics of continuous wastewaters and of harvesting and to analyze the possible impacts of the discharge of these wastewaters and ways to minimize them.

2 Methodology

2.1 Study design

This study monitored the productive process and the major procedures used in semi-intensive tilapia farming. The sample was collected from April to October so as to assess an entire tilapia growth cycle.

The experiment was conducted in Cidreira. Cidreira is located on the northern coast of the state of Rio Grande do Sul, at 30º10'52" S latitude and 50º12'20" W longitude, at an average altitude of 0.60 meters.

The farm analyzed uses a semi-intensive tilapia culture system characterized by the use of fish ponds treated with organic and inorganic fertilizers, with the aim of encouraging natural productivity. A 10-cm layer of sand is placed at the bottom of the tank so that the fish do not come in direct contact with the bottom and with the 5 kg of sheep manure (excrement) used for the development of phytoplankton. The supply of tilapia is only with rations with 46% protein in the first three months after passing the feed ration with 26-30% protein.

2.2 Analytical method

Collection, preservation and analyses of the samples were carried out according to the APHA/AWWA/WPCF standard methods for the examination of water and wastewater (APHA, 2005). The following parameters were measured at the Analytical Center of Universidade de Santa Cruz do Sul. The wastewater was obtained from a brick tank lined with cement measuring 10 x 15 x 1.5 m, containing 141.75 m^3 of water and with 500 tilapia, weighing on average 1 gram, at a density of 3.5 fish per m^3.

2.3 Measurements of environmental parameters – Leopold matrix

The analyses and assessments were made by identification of the several processes used in tilapia farming that produce impacts on the physical, biotic and anthropic environments. The identification and qualitative characterization of impacts were achieved by the interaction matrix derived from the Leopold matrix (LEOPOLD et al., 1971). The Leopold matrix was applied to define the stages of tilapia farming (construction of the pond, water supply, placement of the fish into the pond, feeding, pond water exchange) and the harvesting process (drainage of the water and sludge removal). Within this context, impacting activities were performed, such as soil excavation for pond construction and artesian well drilling for water supply; placement of animal waste and sand at the bottom of the pond for biomass production; electric energy consumption; fish waste in the water; feed residues in the water; water consumption; discharge of wastewater with organic load and discharge of settled sludge. Relevant environmental characteristics included those of the physical, biotic, and anthropic environments.

The probable impacts of the assessed activities or actions on the physical, biotic and anthropic environments represented in the interaction matrix were listed consonant with each environmental element. The impacts were identified based on the relationship between the proposed action and the environmental factor considered and its qualitative characterization.

2.4 Measurements of environmental impacts and estimation of operating parameters

The method and software of the System for Environmental Assessment of Industrial Processes (SAAP) were used to assess the environmental impact parameters. The eutrophication index (EI), rate of dissolved oxygen depletion (RDOD) and environmental pressure index (EPI). The reference legal values were in compliance with CONAMA's resolution 357/2005 (Brasil, 2005) for Class II waters and with Santos's recommendations (SANTOS, 2006).

The eutrophication index was calculated by dividing the total equivalent NO_3^- emissions during the 6 months of collection and was compared with the Brazilian legislation (Brasil, 2006).

The Brazilian legislation is based on the laws established by the U.S. Environmental Protection Agency (EPA), which have a strong international influence.

The economic feed conversion ratio (FCR) (FCR = kg of feed distributed / kg of live weight of fish produced) and the environmental impact category of water dependence (m^3) were also considered. In both cases AUBIN et al. (2009) was used as a reference.

For calculation of RDOD, the values of COD emission during the 6 months of study and the maximum emission established by CONAMA's resolution 357/2005 were used (Brasil, 2005).

The calculation of EPI consisted in establishing weights for the two environmental impact parameters analyzed (EI and RDOD), which was also attained by the use of the SAAP software. The software automatically compiled the parameters and established the weights (SAAP, 2006).

3. Results and Discussion

3.1 Monthly wastewater control

Tables 1 and 2 show the results for the analytical parameters related to wastewaters produced during tilapia farming and harvesting.

Table 1 - Results for the parameters analyzed in semi-intensive tilapia farming.

Parameters	May	June	July	August	September	October
Bicarbonate alkalinity (mg $L^{-1} CaCO_3$)	38.6	8.2	16.5	15.4	9.9	23.1
Carbonate alkalinity (mg $L^{-1} CaCO_3$)	0.0	0.0	0.0	0.0	13.2	0.0
Hydroxide alkalinity (mg $L^{-1} CaCO_3$)	0.0	0.0	0.0	0.0	0.0	0.0
Total alkalinity - mg L^{-1}	38.6	8.2	16.5	15.4	23.1	23.1
Electrical conductivity (mS cm^{-1})	0.118	0.074	0.079	0.092	0.070	0.074
BOD_5 (mg L^{-1} O_2)	13.3	15.2	6.8	20.1	28.5	11.9
COD (mg L^{-1} O_2)	197	103	100	172	174	180
Total phosphorus (mg L^{-1})	0.51	0.12	0.03	0.21	0.10	0.07
Nitrate (mg $L^{-1} N\text{-}NO_3$)	0.9	0.6	0.4	0.6	0.4	0.5
Ammonia nitrogen (mg L^{-1})	5.4	1.7	0.6	<0.1	<0.1	0.2
Thermotolerant coliforms (MPN/100mL)	<80	450	270	<180	<180	<180
pH	9.1	7.2	7.4	10.1	9.8	8.0
Settleable solids (mg L^{-1})	<0.1	<0.1	<0.1	<0.1	<0.1	0.4
Suspended solids (mg L^{-1})	75.0	40.0	26.0	70.0	36.7	52
Turbidity (uT)	29.8	15.5	21.7	22.0	20.5	14
Temperature (°C)	19	14	11	19	15	23

According to Table 1, COD and BOD_5 increase between water catchment and continuous wastewater in semi-intensive tilapia farming, and this may be associated with an increase in the pond's organic content. However, as shown in Table 2, these parameters vary less than expected for harvesting. Notwithstanding, these parameters are higher throughout the process than those established by CONAMA's resolution 357/05 (Brasil, 2005).

In Table 1, the value for thermotolerant coliforms in the catchment water was lower than 20 MPN/100mL, proving to be adequate for aquaculture, as established by CONAMA's resolution 357/05 (Brasil, 2005).

The mean variation in total ammonia concentration during the collection of the continuous wastewater throughout the fattening process is low in relation to the catchment site (Table 1). In harvesting (Table 2), though, it remains practically unchanged, showing that fertilization and most of the feed is not accumulated as organic matter at the bottom of the pond. All values are lower than those recommended by CONAMA's resolution 357/05 (Brasil 2005).

The total alkalinity values shown in Tables 1 and 2 are not comparable to the legal limits established by CONAMA's resolution 357/05 (Brasil 2005). This alkalinity could probably be increasing the pH value, which is also slightly higher than the recommended values.

Turbidity, as well as suspended solids (Table 1), showed an uptrend in relation to harvesting and during farming. This increase can be attributed to unconverted feed residues and to the higher phytoplankton biomass in the pond. For harvesting, as shown in Table 2, turbidity and suspended solid values increase with time, reaching a maximum final value when the material deposited at the bottom of the pond is removed.

BACKMAN et al. (2009) make important correlations of the concentrations of sulfide-free sediments as residue loads to be monitored in a betonic environment. However, in this study, the most important correlations are associated with turbidity and suspended solids owing to the shallow depth of water bodies and turbulence caused by the mobility of the fish.

At harvesting (Table 2), nitrate levels increase but are still much lower than the legal recommendations made by CONAMA's resolution 357/05 (Brasil 2005).

According to Tables 1 and 2 the mean total phosphorus increased in relation to catchment, due probably to the residues from the feed and from fish excrement in the pond during cultivation.

3.2 Harvesting wastewater

With respect to harvesting wastewaters (Table 2), BOD_5 rates showed slight variation while COD varied sharply and suspended solids significantly increased in the last harvesting stage. This was expected because the water reached a nearly empty level whereas turbidity increased too little in the last harvesting stage.

Table 2 - Results for the harvesting parameters analyzed.

Parameters	Sample 1	Sample 2	Sample 3
Bicarbonate alkalinity ($mg\ L^{-1}\ CaCO_3$)	23.1	23.1	6.6
Carbonate alkalinity ($mg\ L^{-1}\ CaCO_3$)	0.0	0.0	17.6
Hydroxide alkalinity ($mg\ L^{-1}\ CaCO_3$)	0.0	0.0	0.0
Total alkalinity ($mg\ L^{-1}$)	23.1	23.1	24.2
Electrical conductivity ($mS\ cm^{-1}$)	0.074	0.073	0.073
BOD_5 ($mg\ L^{-1}\ O_2$)	11.9	10.1	16.4
COD ($mg\ L^{-1}\ O_2$)	180	121	169
Total phosphorus ($mg\ L^{-1}$)	0.07	0.05	0.16
Nitrate ($mg\ L^{-1} N\text{-}NO_3$)	0.5	0.7	0.8
Ammonia nitrogen ($mg\ L^{-1}$)	0.2	<0.1	<0.1
Thermotolerant coliforms (MPN/100mL)	<180	<180	<180
pH	8.0	9.4	9.7
Settleable solids ($mg\ L^{-1}$)	0.4	<0.1	<0.1
Suspended solids ($mg\ L^{-1}$)	52	74	195
Turbidity (uT)	14	10.2	17.2
Temperature (^{o}C)	23	25	23
Chlorophyll (ppm)	18	20.5	28.5

Considering that the highest concentrations of suspended solids are found in harvesting wastewaters, an alternative is to drain the pond more slowly in order to resuspend the solids and improve wastewater quality. The use of a sedimentary basin would be another option. These actions would certainly lessen the impact of harvesting wastewater on water bodies, and would also allow for the reuse of wastewater for irrigation, resulting in rational water use, less fertilizer consumption and lower water pollution (FIGUERÊDO et al., 2005).

The chlorophyll sample data (Table 2) show that no variation occurred in the first and second samples as collections were performed within a very close time interval. A volume of 225,000 L of pond water was obtained in the first collection on October 1, a volume of 125,000 L was collected on October 3, and finally, a volume of 25,000 L was collected on October 8. There was a much higher concentration of chlorophyll in the latter. Chlorophyll concentration substantially increased during harvesting, as expected, due to the greater availability of an eutrophication agent (phosphorus) (VON SPERLING 1994). The major source of this nutrient is uneaten feed and fish excrement, causing the phytoplankton activity to rise. This parameter is much higher than that which is stipulated by CONAMA's resolution 357/05 (Brasil, 2005) throughout the harvest process.

The studies presented by AUBIN et al. (2009) also confirm that wastewater from fish farming activities contains nitrogen and phosphorus, which account for over 90% of the environmental impact through eutrophication. In this case, residual feed is the main source of nitrogen and phosphorus in the aquatic environment.

3.3 Identification of environmental impacts

The respective farming activities were presented in a Leopold interaction matrix (LEOPOLD et al., 1971). Nine impacting activities were identified in the matrix and were multiplied by 16 relevant environmental factors, resulting in 144 possible impact relations, and 60 impacts identified. Of the 60 impacts identified, the following results are presented as subsidy for the proposition of minimizing or enhancing environmental measures. Of all impacts listed 70% were potentially negative and 30% positive, according to the value criterion. As to order criteria, 92% were direct and 8% were indirect. As to the spatial criterion, 90% were local and 10% were regional. As to the temporal criterion, 28% were short-term, 64% medium-term and 8% long-term. As to the dynamic criteria, 35% accounted for permanent impacts, 17% for transient impacts and 48% for cyclical impacts. As to the plastic criteria, 79% accounted for reversible impacts and 21% for irreversible impacts.

Although the profiles of the impacts associated with value and order criteria indicate potential environmental damage, the analytical quantitative data expressed as environmental pressure index (EPI) (Table 3) shows values of 2.47 with significant contribution of a RDOD of 3.28.

Proposal of environmental measures for cleaner production

The major environmental problems identified in this activity are shown in Table 3. Proposals for cleaner production can be divided into actions towards minimizing the impacts of the construction of the farming unit (Phase 1-3), towards minimizing operational impacts (Phase 4-7) and towards optimizing reuse actions concerning effluent and wastewater disposal (Phase 8-9).

The FCR sets the value of 7.21 considering the production of 475 tilapia with an overall harvest weight of 237 kg. OSOFERO et al. (2009), who also investigated tilapia cultures, found an FCR of 2.15 in a three-month growth period whereas the present study contemplates a six-month period. Comparatively to the data obtained by AUBIN et al. (2009), the values calculated here are at least four times greater than for the culture of trout and sea-bass. Our system has a worse performance because less feed is converted, causing waste of feed and increasing the environmental impact, thus resulting in a higher RDOD.

Table 3 - Proposal for cleaner production in semi-intensive tilapia farming.

Major problems	Measures to minimize negative impacts and to enhance positive ones
Phase 1 – Construction of the pond. Soil excavation.	To minimize civil construction impacts with excavated tank.
Phase 2 – Well drilling.	More advantageous than irrigation through a water body.
Phase 3 – Deposition of organic matter into the tank. Excrement.	Good alternative in terms of costs and for avoiding the use of chemical fertilization.
Phase 4 – Water input. Electric power consumption (pump).	The excavated pond facilitates water transfer from the well owing to its declivity. As a result, the use of electrical power is lower.
Phase 5 – Addition of fingerlings. Excrement in water.	More appropriate ratios between volume of species and pond volume. It is impossible to avoid fish excrement in the water, so it is important to use an amount of fingerlings that matches the tank size, thus avoiding high organic load and biomass accumulation.
Phase 6 – Feeding. Feed residues in water.	It is important to control the quality and amount of animal feed. Monitoring and optimization of the economic feed conversion ratio (FCR).

Phase 7 – Water renewal. Water consumption.	Optimization of rates of water renewal in the pond to determine the time of maximum water retention.
Phase 8 – Water disposal. Wastewater with organic load.	The wastewater is reused for watering the vegetable garden and pastureland.
Phase 9 – Sludge removal. Pasty organic load.	The organic load can be converted to manure, mixed with the soil in plowland.

4. Conclusions

The stocking density per m^3 of water could be increased by nearly 40% in relation to the average stocking density recommended in the literature.

Actually, wastewaters are the major environmental impact, especially due to the chemical oxygen demand. However, this impact can be minimized by the use of appropriate average stocking density, then will there be conversion of the feed into removable protein, and not only into decaying biomass, for sludge accumulation.

With respect to other physical, chemical, and biological parameters assessed in this study, no environmental impacts were detected. This may be associated with drainage of water from ponds with a small flow rate and with the effective phase separation of settled sludge.

Therefore, the use of wastewater for irrigation is the best alternative for the rational use of water, lower fertilizer utilization and reduction of water pollution. Recirculation could be another alternative, which rationalizes energy consumption for water catchment, in addition to reducing the release of nutrients and organic matter into the receiving bodies.

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