XVII[th] World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

AQUACULTURE IN GREENHOUSE

M.C. GALERA QUILES[1], G. LOPEZ DIAZ[2], M.C MANJON RODRIGUEZ [3]

[1] Fundación para las Tecnologías Auxiliares de la Agricultura. Ctra. Sacramento sn/ (sede PITA en UAL). 04120, La Cañada de San Urbano (Almería). mcgalera@fundaciontecnova.com
[2] Fundación para las Tecnologías Auxiliares de la Agricultura. Ctra. Sacramento sn/ (sede PITA en UAL). 04120, La Cañada de San Urbano (Almería). glopez@fundaciontecnova.com
[3] Fundación para las Tecnologías Auxiliares de la Agricultura. Ctra. Sacramento sn/ (sede PITA en UAL). 04120, La Cañada de San Urbano (Almería). mcmanjon@fundaciontecnova.com

CSBE100955 – Presented at Section II: Farm Buildings, Equipment, Structures and Livestock Environment

ABSTRACT. The main socio-economic sector of the province of Almería (Spain) is based on agriculture via the cultivation of fruit and vegetables in greenhouses, which represent 40% of its economic activity. The 27.000 hectares of greenhouses have generated a business cluster with added value through applied research and development. The auxiliary industrial sector around agriculture has a turnover of around € 2,000 million. The profitability of traditional farms and companies of the auxiliary industry for agriculture has been compromised in recent years due to the liberalization of markets, making it necessary to diversify production under plastic greenhouses. As an alternative to this market shift the development of intensive aquaculture systems of tilapia (*oreochromis niloticus*) under plastic cobered greenhouses was established. Researchers have worked on the development of a greenhouse structure specifically designed for growing tilapia in the climatic conditions of the Mediterranean. To do so we have relied on the experience of the technological centre tecnova that has experience in designing greenhouses structures as well as major construction companies involved in building greenhouses in the province. The project has assessed the technical and economical feasibility of performing intensive aquaculture farming systems in a greenhouse. Also it proposes a model of sustainable aquaculture farming and discusses the feasibility of integrating tilapia aquaculture in obsolete greenhouse structures as a means of revitalising the economic sector.

Keywords: greenhouse structures, Tilapia, aquaculture

INTRODUCTION

Protected agriculture is an economic model of success in many areas of the planet, especially in the Mediterranean area. The area of protected crops in the world is between four and five million hectares, including farming techniques such as mulching, the microtunnels, covered and greenhouses. Focusing on greenhouse cultivation can identify two major areas of this type of culture: South East Asia (China, Japan and Korea) with approximately one million six hundred thousand hectares of cropland (including greenhouses and high tunnels) and the Mediterranean area, with two hundred thousand hectares *(Castilla, 2009).* Within the Mediterranean Spain represents the largest concentration of greenhouse area with fifty-two thousand hectares, of which approximately 52% are located in the province of Almeria (*Baeza, 2007*). This concentration of greenhouses in the Almeria area of business has created a business cluster named assistant agriculture industry representing a turnover of around 2,000 million of EURO. However, in recent years the profitability of traditional farms and businesses in the auxiliary industry has been affected due to the liberalization of markets; making it necessary to diversify production under plastic. As an alternative to this problem is the development of intensive aquaculture systems under plastic within a closed cycle production. The global demand for fishery products has increased eightfold since 1950, motivated both by increase of global population and the rising consumption of fishery products, wich in the year 2007 was 19.7 kg / person / year (APROMAR, 2009).

To face up this growing demand, capture fisheries must be supplemented by aquaculture. According to FAO, 2009, it is considered that aquaculture contributes effectively to food security, poverty reduction and economic development with minimum environmental impact and maximum benefit to society. The main species produced by aquaculture in the world (by tonnage), Nile Tilapia (*Oreochromis niloticus*) is founded as the tenth species in volume production (FAO, 2009).Spanish aquaculture production reached 43,966 tons in 2008 (APROMAR, 2009), producing species such as bream, sea bass, turbot, sea bass, sole or eel. Nowadays, the search for new species and system productions is focused on crop species that requires a low animal protein feeding, which improve the quality of effluents in crop production and foster environmentally sustainable production.

In this sense, the culture of Tilapia in Spain under controlled conditions is an interesting alternative of study because it has some very positive qualities and skills for success as their ease of culture, as it adapts easily to a wide range environments, it has a high reproductive rate, high disease resistance, high survivability and is able to grow well in a wide range of physical-chemical qualities of water. Furthermore, it has a high quality product (white meat, solid, tasty and very nutritious) to the consumer.In the present study we have evaluated the technical and economic possibilities for growing tilapia in Spain in greenhouse structures under Mediterranean conditions. The profitability of this crop and its cultivation as an alternative farming needs the compromise of designing energy-sufficient farms due to that the major tilapia producing areas in the world are characterized by low production costs and growing in small ponds. It has been evaluated the “Almería type greenhouse”, which represents the 96,5% of the covered area in Almería (*Fernández, 2004*), thanks to things like the versatility to adapt to the plots, the economy in its construction compared to industrial structures such as greenhouses multi-tunnel and venlo, and the high adaptation to climatic conditions and local production. It is characterized as a tense-structure with vertical elements such support-pillars and horizontal elements forming a grid of wires and strands pretensioned that determine the resistance and structural performance. Greenhouse structures, materials used and the embodied technology evolve and shape depending on the climatic characteristics of the development zone, crops to be implemented and the desired technological level. Thus the use of lightweight structures and enclosures with flexible materials are typical of the Mediterranean area (Von Elsner et al., 2000a and 2000b).

MATERIAL AND METHODS

To assess the technical feasibility and economic culture of tilapia in a greenhouse in Mediterranean areas has taken the following methodology:

- Study of crop species more suited to intensive cultivation in greenhouse
- Realization of heat balance in traditional greenhouse structure in the Mediterranean area to meet the thermal requirements and the viability of growing under these conditions
- Design of greenhouse structure

Crop species. It has been evaluated the main species of farmed tilapia: *Oreochromis aureus, O. Mossambicus* and *Niloticus* with previous research developed on Tilapia culture (Dadzie, 1981; Abu Hena et al, 2005; Wicki, 1998) about growth, weight and length reached, conversion rates or diseases resistant and conditions for cultivation (culture temperature, salinity tolerated, pH, oxygen, ammonia, nitrites, alkalinity and water hardness).

Heat balance in "Almeria type greenhouse". The boundary conditions considered to evaluate the theoretical thermal behaviour of commercial Tilapia tanks in greenhouse structures were as follows:

- Temperature setpoint of the water: 26ºC.
- Cultivation under Almería type greenhouse (32x32 meters: 1024 m^2)
- Covering materials: Three layers plastic and insect nets in windows
- Breeding Tanks: 14 commercial Tilapia Tanks (12 m x 12 m x 0,95 m) placed on land
- Climate data taken from annual averages of greenhouses of similar characteristics to that proposed in the province of Almeria.

It has been taken into account the following losses and gains of energy in the heat balance of commercial tanks of Tilapia situated in greenhouse (Figure 1)

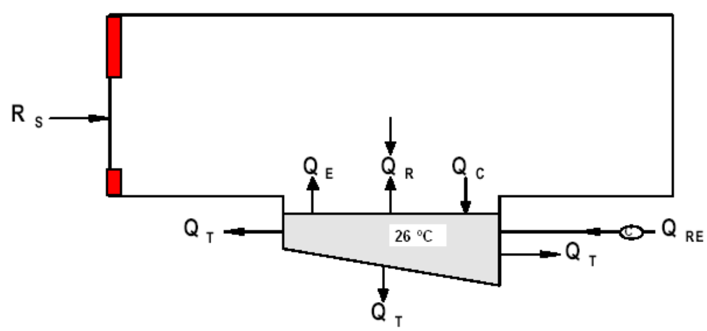

Figure 1. Heat Balance in breeding tanks

Figure 1 legend:

Q_E Energy of Thermal evaporation of water in the tank
Q_R Energy of Thermal heat radiation by temperature differences
Q_C Energy of Thermal Convection between water and air
Q_T Energy of Thermal Transmission water by the tank
R_S Energy of Thermal Solar Radiation
Q_{RE} Energy Thermal of Renewal of water in the tank

Gains and losses of heat in the breeding tanks have been calculated with the following formulas

Energy of Thermal evaporation of water in the tank (Q_E). The mass of water evaporated from the breeding tanks has been calculated by the Bernier´s formula to free water surfaces.

$$M_e = \left(\frac{16}{3600}\right) * S * \left(W_e - W_a\right)$$

M_e Mass of water evaporated (kg/s)

W_e Absolute humidity at saturation at the temperature of the breeding tank $\left(\frac{kg_{water}}{kg_{air}}\right)$ fixed at 26ºC for the correct development of Tilapia

W_a Absolute humidity of the ambient air temperature $\left(\frac{kg_{water}}{kg_{air}}\right)$

S Water surface area $\left(m^2\right)$

With the mass of water evaporated we can calculate the heat loss of the water due to evaporating process

$$Q_e = M_e * C_{lat}$$

Q_e Heat lost by evaporation (J)

M_e Mass of water evaporated (kg)

C_{lat} Water latent heat (2.434.000 J/kg)

Energy of Thermal heat radiation by temperature differences(Q_R).Heat losses by heat radiation are computed using the Stefan-Boltzmann formula. The radiation losses are a function of the difference between the average temperature of the tanks and water.

$$Q_R = D * E * \left(T_{ag}^4 - T_c^4\right)\left[\frac{w}{m^2}\right]$$

$D = 5{,}67x10^{-8} \frac{w}{m^{2\,\circ} k^4}$ Stefan-Boltzmann constant

$E = 0{,}95$ water emissivity

T_{ag} water temperature (ºk)

T_c tanks temperature (ºk)

Energy of Thermal Convection between water and air (Q_C). To assess the loss by natural convection between the body of water and air, considering both fluids at rest, is used the formula of Newton's law of cooling

$$Q_C = h * S * \left(T_{ag} - T_{amb}\right)\left[\frac{w}{m^2}\right]$$

$h = 30 \frac{w}{m^{2} {}^{o} k}$ Convection coefficient of water stand in air at rest

S Water surface area (m^2)

T_{ag} Water temperature (ºk)

T_{amb} Air temperature (ºk)

Energy of Thermal Transmission water by the tank (Q_T). The transmission losses depend on the tank´s material.

$$Q_T = C_T * S * (T_{ag} - T_{amb}) \left[\frac{w}{m^2} \right]$$

$C_T = 2{,}7 \frac{w}{m^{2} {}^{o} k}$ Heat transfer coefficient

S Water surface area (m^2)

T_{ag} Water temperature (ºC)

T_{amb} Air temperature (ºC)

Energy of Thermal Solar Radiation (R_S). Energy of thermal solar radiation in the greenhouse structure (data collected from historical averages in similar greenhouses)

Greenhouse structure design. The greenhouse structure designed has been calculated using finite element method to verify their resistance to the actions determined by national legislation. For the design of the greenhouse structure it has been taken into account the heat balance data produced

RESULTS

It has been assessed the feasibility of tilapia culture in greenhouses under Mediterranean conditions. It has been selected *O. niloticus* and commercial hybrids monosex (only males) as tilapia species optimal for intensive cultivation under greenhouse conditions in Almeria. This specie (Figure 2) is one of the toughest in terms of survival and has a good feed conversion rate also is one of the most cultivated species worldwide, accounting for 80% of all farmed tilapia (FAO, 2009).

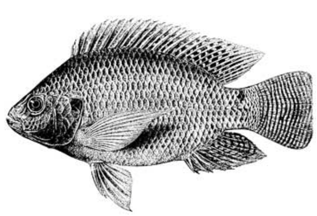

Figure 2: *Oreochromis niloticus*

The main characteristic of the genus *Oreochromis* taken into account in the design of structures and facilities for growing in greenhouses has been the water temperature for

optimal growth, establishing a setpoint temperature of 26 ° C. The theoretical thermal balance on comercial tilapia tanks in a Almería type greenhouse shows the following results:
Table 1, reflect the gains and losses calculated for the firsts days of January, one of the worst months. Heat losses are reflected in W (J/s) on a breeding tank, the losses are considered as negative values and positive values gains.

	QE (W)	QR (W)	QC (W)	QT (W)	Q Rs (W)	Q (W)
01/01/200X	- 3.396,89	- 1.209,90	- 6.624,00	-4684,68	1900	- 14.015,47
02/01/200X	- 3.478,84	- 1.284,92	- 7.056,00	-4258,8	600	- 15.478,56
03/01/200X	- 3.383,09	- 1.197,36	- 6.552,00	-4350,06	500	- 14.982,51
04/01/200X	- 2.775,06	- 697,77	- 3.744,00	-4593,42	2000	- 9.810,26
05/01/200X	- 2.927,11	- 814,84	- 4.392,00	-4623,84	1800	- 10.957,79
06/01/200X	- 2.466,46	- 473,69	- 2.520,00	-4045,86	1900	- 7.606,01

Table 1. Heat Balance in breeding tank

Figure 3 presents the theoretical thermal model for 2008 of a tilapia breeding tank under greenhouse conditions in Almeria.

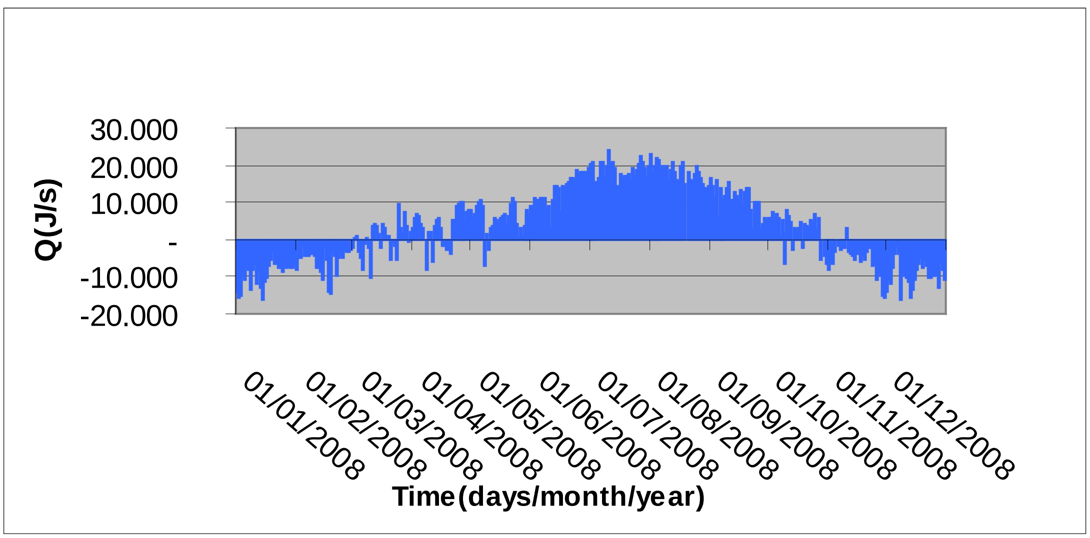

Figure 3. Total heat flux in breeding tank

In Figure 4 are represented in percentage sources of heat loss in breeding tanks.

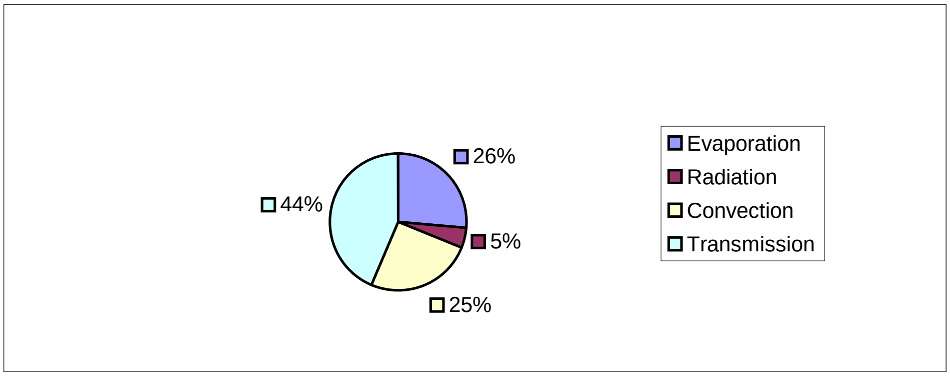

Figure 4. Sources of heat loss in breeding tanks

Figure 5 depicts the temperature of the water obtained in a year means under a greenhouse climate Almeria type (without additional heat input).

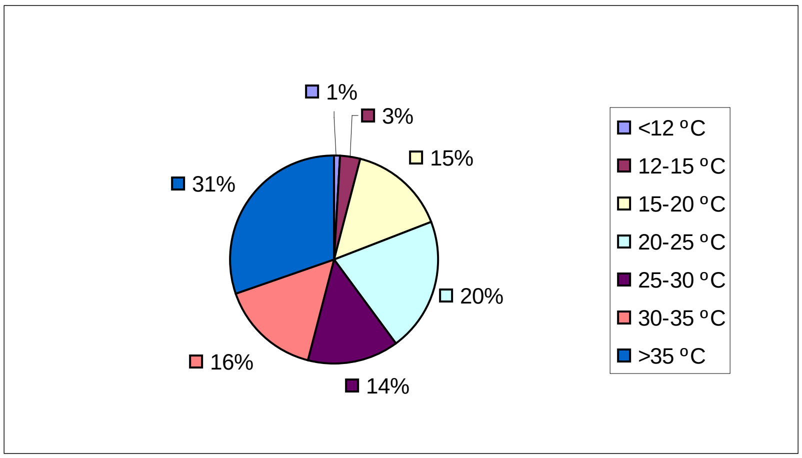

Figure 5. Water temperature in breeding tanks without additional heat

As a result of process about analysis and design of the greenhouse structures specifically designed for tilapia aquaculture, is raised the following amendments and recommendations on the structure of greenhouses for Tilapia crop:

- Symmetrical gable roof
- Greenhouse axis orientation North-South
- Width span: 6,4 m
- Covering material: compact Polycarbonate
- Gutter height of 3.5 m
- Maximum height of 4.7 m, roof angle 20-25º
- Installation of special gutters to collect water from condensation
- Lateral windows in greenhouse, without nets or polycarbonate, about 1.5 m of width

Figure 6 shows the greenhouse structure proposed for intensive aquaculture of tilapia.

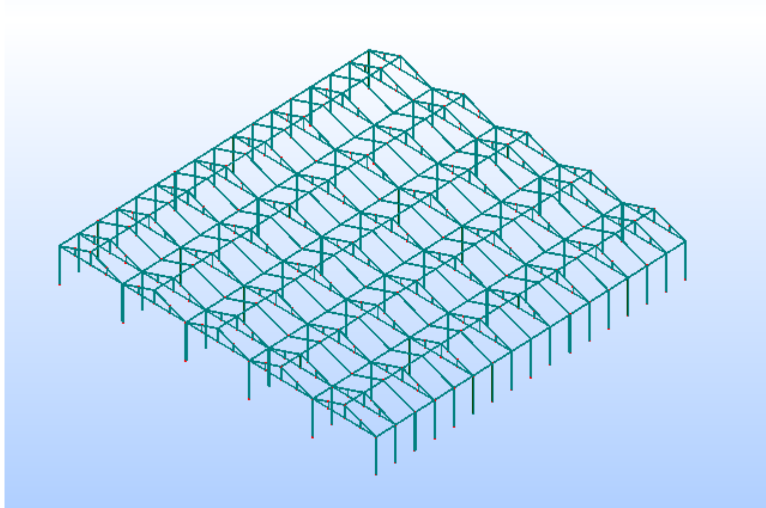
Figure 6. Proposed greenhouse structure

CONCLUSION. Tilapia farming in "Almería type greenhouses" in the Mediterranean area has a high potential, since environmental conditions generated by these structures may, depending on the values of heat balance simulation, provide a temperature holding on breeding tanks for more of the 60% of the days of the year. The months in which there is a negative balance of heat (decrease in water temperature below 26 º C) are January, February, November and December. Traditional greenhouses structures such "Almería type greenhouses" can be reused for Tilapia Aquaculture, by means of additional heat source in colder months for the continued cultivation, and corrective measures to prevent heat loss from the breeding tank water, mainly due to transmission phenomena and evaporation from the water layer. As corrective actions is proposed thermal insulation for the walls of the breeding tanks and the use of thermal blankets in winter and shading mesh on the surface of water in summer, to improve the thermal performance and prevent water loss through evaporation. With the information obtained from the thermal performance of tilapia breeding tanks is proposed a greenhouse structure optimized for tilapia aquaculture. This structure enables a better performance of the water temperature without additional heat input and offers the possibility of integrating renewables as solar photovoltaic panels in the structure such as medium of thermal support. The most appropriate species of tilapia for culture in Mediterranean areas is O. niloticus. However, other species of fish can be grown under greenhouse like carp (Cyprinus carpio), tench (Tinca tinca) or eel (Anguilla anguilla).

Acknowledgements. This Project has been developed by the Technological Centre for Auxiliary Industry for Agriculture, TECNOVA with funding from Andalusian Government (Spain) with FEDER funds and the collaboration of the Technological Centre of Aquaculture of Andalusia and greenhouses constructor companies Ferrer, Agroinver, Novedades Agrícolas, Tecnoponiente and Frada.

REFERENCES

Abu Hena Md. Mostofa Kamala, Graham C. Mairb,T. 2005. Salinity tolerance in superior genotypes of tilapia, Oreochromis niloticus, Oreochromis mossambicus and their hybrids. Aquaculture 247 (2005) 189– 201

APROMAR, 2009. La acuicultura marina de peces en España.
Baeza, E. 2007. Optimización del diseño de los. Sistemas de ventilación en invernadero tipo parral. (Tesis doctoral)
Castilla, N. 2009. Sistemas productivos en horticultura protegida. XVIII Congreso Internacional CIPA 2009
Castro Rivera, R.; Paz, J. Aguilar, G. 2004. Evaluación del crecimiento de alevines de tres especies de Tilapia (Oreochromis sp.) en aguas duras, en la región de la Cañada, Oaxaca, México. Acuatic. ISSN 1578-4541, Nº. 20, 2004 , pags. 38-43
Dadzie, S. 1981. Species combination in tilapia culture. Department of Zoology. University of Nairobi. Nairobi, Kenya.
The State of World Fisheries and Aquaculture (SOFIA) 2008. FAO. Departamento de Pesca. Roma. 2009
Von Elsner B., Briassoulis D., Waaijenberg D., Mistriotis A., Zabeltitz von Chr., Gratraud J., Russo G., Suay-Cortes R. 2000a. Review of structural and functional characteristics of greenhouses in European Union countries: Part I: Design Requirements. J.Agric.
Von Elsner B., Briassoulis D., Waaijenberg D., Mistriotis A., Zabeltitz von Chr., Gratraud J., Russo G., Suay-Cortes R. 2000b. Review of structural and functional characteristics of greenhouses in European Union countries: Part II: Design Requirements. J.Agric. Engng Res., 75:111-126
Wicki, G.A. (1998). Estudio de desarrollo y producción de Tilapia (Oreochromis niloticus) Revista AquaTIC, 2, ISSN 1578-4541