International Biodeterioration & Biodegradation 102 (2015) 107–115

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Biological nutrient removal by recirculating aquaponic system: Optimization of the dimension ratio between the hydroponic & rearing tank components

Su Shiung Lam [a, c, *], Nyuk Ling Ma [b], Ahmad Jusoh [a], Mohd Azmi Ambak [c]

[a] Eastern Corridor Renewable Energy Group (ECRE), School of Ocean Engineering, University Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia
[b] School of Fundamental Science, University Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia
[c] Institute of Tropical Aquaculture, University Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

ARTICLE INFO

Article history:
Received 30 December 2014
Received in revised form
8 March 2015
Accepted 9 March 2015
Available online 2 April 2015

Keywords:
Nutrient removal
Aquaponic
Hydroponic
Aquaculture
Marble goby

ABSTRACT

Marble goby (*Oxyeleotris marmorata* Bleeker) was cultured in a recirculating aquaponic system (RAS) containing a hydroponic tank grown with water spinach (*Ipomoea aquatica*). The influence of component ratio (hydroponic tank volume to rearing tank volume) on the fish growth, vegetable yield, and nutrient removal was investigated. Increased fish growth (2.4 g/day), vegetable yield (22 kg/harvest), and nutrient removal (83% ammonia-N removal, 87% nitrite-N removal, 70% nitrate-N removal, 60% removal of total phosphorus, 88% removal of total suspended solid, 63% removal of 5-day biochemical oxygen demand) were observed at high component ratio (3 m^3/m^3). Component ratio was found to have a significant influence on nutrient removal and production of marble goby and water spinach in RAS. A component ratio of $\geq$3 m^3 of hydroponic tank volume to 1 m^3 of fish rearing tank volume showed advantages in improving the production of the fish and vegetable and removing the nutrient wastes, TSS, and BOD_5 generated from the culture of the fish. The results indicate that RAS show exceptional promise as a means to the reduction of biological nutrients accumulated in aquaculture wastewater and in turn providing a good water quality environment for fish culture.

Introduction

Marble goby (*Oxyeleotris marmorata* Bleeker) is a freshwater food fish that commands a high price in Southeast Asia, ranging from a wholesale price of 20–30 US dollars/kg (Lam et al., 2008; Chew et al., 2009; Loo et al., 2013). The fish is conventionally cultured in lakes, rivers, and ponds in countries such as Malaysia, Thailand, and Vietnam (Luong et al., 2005; Chew et al., 2009; Loo et al., 2013). Some attempts to culture the fish in earthen ponds and cages have failed because of the disease problem caused by *Aeromonas hydrophila* and *Lernaea cyprinacea* (anchor worm), the slow growth of the fish during juvenile stage, and the high fish mortality rate (Ang Kok, 1980; Cheah et al., 1994; Tng et al., 2008; Nhi et al., 2010; Idris and Amba, 2011). It is thought that these problems are derived from the poor water quality and the lack of appropriate control present in the conventional culture of marble goby. Therefore, it is important to find an alternative culture technique that could rectify these deficiencies in order to ensure better production of the fish.

Recirculating aquaponic system (RAS), a water recirculating system that is designed to produce both fish and plants, can potentially be a good culture technique for the fish as it ensures a good controlled culture condition by providing better control of water quality, reduced water usage, improved waste management and nutrient recycling (Hamlin et al., 2008; Endut et al., 2009; Martins et al., 2010; Lam et al., 2014). In RAS, the biological nutrient wastes excreted by fish (e.g. ammonia) and those generated from the microbial breakdown of fish feed (nitrite, nitrate) are absorbed by plants as nutrients for growth, and thus this method allows the removal of undesirable nutrient wastes from the water by plants and the water can then be reused for fish culture. These could potentially lead to faster growth and higher production of

* Corresponding author. Eastern Corridor Renewable Energy Group (ECRE), School of Ocean Engineering, University Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia. Tel.: +60 (9) 668 3844; fax: +60 (9) 668 3991.
E-mail addresses: lam@umt.edu.my (S.S. Lam), nyukling@umt.edu.my (N.L. Ma), ahmadj@umt.edu.my (A. Jusoh), ambak@umt.edu.my (M.A. Ambak).

http://dx.doi.org/10.1016/j.ibiod.2015.03.012
0964-8305/

both the fish and plants. The use of RAS techniques has been reported to be highly efficient as it utilizes the generated fish waste as nutrients for the plants and thus providing a symbiotic environment for producing fish and plants in a closed system (Martins et al., 2010). However, the need for viable methods for protection of plants grown in RAS is currently under development as there has not been a fish-safe insecticide or fungicide developed for use in aquaponics (Pilinszky et al., 2015). There is also a need to design the RAS to maintain the balance of nutrient production and uptake in order to ensure effective nutrient removal (Buzby and Lin, 2014).

Owing to the tremendous market demand for marble goby and the limitations and poor fish yield shown by conventional culture methods, it was thought useful to investigate the development of a RAS for efficient control of water quality and improved fish production from the culture of the fish. The distinct advantages shown by RAS may overcome the poor growth and disease problem shown by conventional cage and pond culture systems and lead to the potential for the greater production of the fish. So far, limited information is available on the characteristics of the culture of marble goby. Studies on the application of RAS have been reported in the culture of other species, such as seabass (Franco-Nava et al., 2004), African catfish (Endut et al., 2010) and carp (Martins et al., 2009), however, no similar studies have been reported on marble goby.

In this study, marble goby was cultured in a fish rearing tank treated by a RAS containing a hydroponic tank grown with leaf vegetable (i.e. water spinach, *Ipomoea aquatica*). The influence of the dimension ratio between the hydroponic tank and the fish rearing tank (termed “component ratio”, i.e. hydroponic tank volume to rearing tank volume) on the fish growth, vegetable yield, and nutrient removal was investigated; ammonia-N (TAN), nitrite-N (NO_2–N), nitrate-N (NO_3–N), total-N (TN), 5-day biochemical oxygen demand (BOD_5), total suspended solid (TSS), and total phosphorus (TP) were determined and assessed for this study. The component ratio is an important process parameter to study as it could have influence on the rate and extent of nutrient accumulation and removal in the fish rearing tank, and also the nutrient supplementation to the plants in the hydroponic tank; these two factors could have effects on the production of both the fish and the plants in the RAS. These evaluations are important to assess the technical feasibility of using RAS as an alternative method for the culture of the fish. So far, there has been little research reported on the influence of the component ratio used in RAS, and existing literature is limited to mostly studies performed on the use of RAS for the culture of tilapia, catfish, tomato, and pak choi (*Brassica campestris* L. *subsp. chinensis*) (Palm et al., 2014; Hu et al., 2015).

Materials and methods

Design of recirculating aquaponic system (RAS)

The RAS developed and used for this investigation is shown in Fig. 1. It consists of fibreglass fish rearing tank, hydroponic tank, denitrification sump, rapid sand filter tank coupled with filter floss for solid removal, and aerated water reservoir tank.

Three fibreglass fish rearing tank were set up in series for the culture of marble goby. Air stones connected to an air blower were diffusely placed into the rearing tanks in order to maintain sufficient oxygen supply to the fish. The water level in the rearing tanks was maintained at a height of 0.85 m in order to achieve a water volume of about 1000 L. The loss of water from evaporation, transpiration, and sludge removal was replenished with water from the aerated water reservoir tank. The rearing tanks were covered with 20 mm plastic net to prevent the fish from jumping out of the tanks. The temperature, level of dissolved oxygen (DO), and pH of water in the rearing tanks were performed in situ through the use of YSI multi-probe meter (YSI 550A model) and pH meter (Cyber Scan waterproof). The water temperature was found to be in the range of 27–28 °C, and the pH was in the range of 7–8, and the level of DO was monitored at >6 mg/L; the water quality parameters were reported to be suitable for the culture of marble goby (Lam et al., 2008).

Water effluent from the fish rearing tanks was first treated by an aerated hydroponic tanks (1–10 m^2 area, 0.5 m height of water) grown with leaf vegetable (i.e. water spinach, *Ipomoea aquatic*). The effluent was sprinkled over the vegetables in the hydroponic tank where the undesirable nutrient wastes (e.g. ammonia, nitrite, nitrate) produced from both the fish and the fish feed were absorbed and recovered by the plant as nutrient. Water spinach were planted on polystyrene sheets that floated along the hydroponic tank; the polystyrene sheet supported the plants at the water surface with roots suspended in the culture water, providing good exposure of the roots to the culture water while preventing undesired clogging.

The effluent from the hydroponic tank was then allowed to trickle down to a well-sealed sump for denitrification treatment. The denitrification sump was incubated with denitrifying bacteria in order to convert the remaining nitrate in the effluent to nitrogen gas under anaerobic condition. The different components in the RAS were assembled at different heights such that the water was flowed under gravity. The effluent from the denitrification sump was then pumped vertically to the rapid sand filter tank filled with sands and filter floss of different thicknesses for solid removal. Finally, the effluent from the sand filter tank was channelled into an aerated water reservoir tank filled with crushed coral, which serves as a buffering substrate to maintain a pH of 7.5 ± 0.5 in the RAS system. The treated water was then returned to the fish rearing tank by gravity. PVC pipelines were used to circulate water between the fish rearing tank and the RAS components. The water flow rates were controlled by the gate valves installed in the RAS.

Fish and acclimation

Marble goby with a body weight of approximately 100 g was obtained from various local sources. Before experiments, the fishes were acclimated individually in fibreglass holding tanks supplied with a continuous flow of well-aerated fresh water (water temperature: 27 °C; pH: 7.5; DO > 6 mg/L). The water was passed through a UV disinfection unit before being supplied to the holding tanks in order to ensure the water is disease free. During acclimation, the fish were fed to satiation once a day with live tilapia (*Oreochromis niloticus*). Live tilapia was selected for this study due to its ease of acquisition and its suitability as a feed to marble goby as has been reported by previous studies (Lam et al., 2014), and the fact that marble goby is a passive carnivorous fish and there is virtually no suitable artificial feed for the fish.

Experimental details on the influence of component ratio

Experimental procedure

The experiment was conducted in fish rearing tanks treated by RAS (see Section 2.1) with the water temperature maintained at 27 °C, pH controlled at 7.5, and the level of DO monitored at > 6 mg/L. The fish rearing tanks were subjected to natural 24-h light: dark cycle (i.e. 12 h of light photoperiod: 12 h of dark photoperiod).

The variable to be studied was the dimension ratio between the hydroponic tank and the fish rearing tank (termed “component ratio”, i.e. hydroponic tank volume to rearing tank volume). Six component ratios of hydroponic tank volume to rearing tank volume were selected and assessed for this study, namely ½ m^3:1 m^3, 1 m^3:1 m^3, 2 m^3:1 m^3, 3 m^3:1 m^3, 4 m^3:1 m^3, and 5 m^3:1 m^3 (Table 1). The different hydroponic tank volumes were achieved through the use of 6 hydroponic tanks with different areas (i.e.