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A study on the optimal hydraulic loading rate and plant ratios in recirculation aquaponic system

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ABSTRACT

The growths of the African catfish (*Clarias gariepinus*) and water spinach (*Ipomoea aquatica*) were evaluated in recirculation aquaponic system (RAS). Fish production performance, plant growth and nutrient removal were measured and their dependence on hydraulic loading rate (HLR) was assessed. Fish production did not differ significantly between hydraulic loading rates. In contrast to the fish production, the water spinach yield was significantly higher in the lower hydraulic loading rate. Fish production, plant growth and percentage nutrient removal were highest at hydraulic loading rate of 1.28 m/day. The ratio of fish to plant production has been calculated to balance nutrient generation from fish with nutrient removal by plants and the optimum ratio was 15–42 gram of fish feed/m^2 of plant growing area. Each unit in RAS was evaluated in terms of oxygen demand. Using specified feeding regime, mass balance equations were applied to quantify the waste discharges from rearing tanks and treatment units. The waste discharged was found to be strongly dependent on hydraulic loading rate.

1. Introduction

Aquaculture probably the fastest growing food-producing sector, now accounts for almost 50% of the world's food fish and is perceived as having the greatest potential to meet the growing demand for aquatic food. It is estimated that at least an additional 40 million tonnes of aquatic food will be required by 2030 to maintain the current per capita consumption (FAO, 2006).

When fish are cultured, only a small proportion of the feed is converted (25–30%) to useable energy (Rakocy et al., 1993). The balance of nutrients is excreted in solid and dissolved fractions. Dissolved nutrients accumulate in recirculation systems with low water exchange and high feeding rates to levels which approximate hydroponic nutrient solutions.

Recirculation aquaponic system (RAS) is a promising technology in the integration of fish and hydroponic plant production. The fish water, rich in nutrients is used for plant growth, while the plants are used as biofilters for water regeneration. Whilst biofiltration converts the harmful into the harmless, the end point is a buildup of nutrients within recirculation systems, principally consisting of nitrates and phosphates. Nutrient removal by plants improves the quality of effluent and may enhance fish production. The amount of nitrate produced in a fish culture system is directly proportional to two factors: the amount or density of fish in the system and the amount and protein content of the food, as different fish species require different protein content in their respective diets.

Integrated systems use water more efficiently through the interacting activities of fish and plants. The addition of water to a fish tank to satisfy the oxygen requirements depends on the oxygen consumption of the fish, the oxygen concentration in the inlet water and the lowest acceptable concentration in the outlet water (Lekang, 2007). Hence effective HLR can be employed to achieve optimal growth for the fish and plants.

The rate of change in nutrient concentration can be influenced by varying the ratio of plants to fish (Rakocy et al., 2006). However, since the relative proportions of soluble nutrients made available to the hydroponic plants by fish excretion do not mirror the proportions of nutrients assimilated by normally growing plants, the rates of change in concentration for individual nutrients differ. The disparity in accumulation or reduction rates of different nutrients quickly results in suboptimal concentrations and ratios of nutrients, thereby reducing the nutritional adequacy of the solution for plants. Theoretically, the nutrient content of a diet can be manipulated to make the relative proportions of nutrients excreted by fish more similar to the relative proportions of nutrients assimilated by plants. With such a diet, there would be an optimal

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ration of fish to plants and optimal nutrient supplementation (Seawright et al., 1998).

Several mass balance models have been proposed from previous studies (Pagand et al., 2000; Papatryphon et al., 2005; Schneider et al., 2005; Mongirdas and Kusta, 2006), from which the total nitrogen and phosphorus discharges into receiving waters can be estimated. However, most of these studies were conducted in open systems. Recently, the incorporation of recirculated fish with vegetable hydroponics production has become an interesting model to private sector, aquaculture and environmental scientists (Rakocy et al., 2006; Bakhsh and Shariff, 2007; Endut et al., 2009).

The objectives of this study were to (1) determine the optimum hydraulic loading rate in term of fish production, plant production, and nutrient removal, (2) evaluate the optimum plants ratio in term of daily fish feed input to plant growing area, and (3) study the mass balance of oxygen in achieving sustainable balance between fish and plants.

2. Methods

2.1. Experimental design

The recirculation aquaponic system (RAS) utilized is depicted in Fig. 1. The experimental facility was located in a greenhouse of the University of Malaysia Terengganu campus. RAS consisted of a fiberglass rearing tank, hydroponic trough (growing bed), sand filter for solid removal, sump system for denitrification unit, water holding tank and reservoir (pre-aeration). Pipelines made of polyvinyl chloride were installed to connect the culture tank and hydroponic trough to recirculate the water.

Three culture tanks arranged in series were used in the rearing of African catfish (*Clarias gariepinus*). Air stones, connected to an air blower were installed in the culture tank to supply oxygen for fish culture. Water level in each culture tank was kept at 0.85 m deep to maintain the water volume at 1000 L. Water lost through evaporation, transpiration and sludge removal was replenished with water in the pre-aeration tank. The tank openings were covered by plastic net (20 mm aperture) to hinder the fish jumping out of the tanks. Measurements of temperature, dissolved oxygen (DO) and pH of water samples were performed in situ during the sampling process using the YSI multi-probe meter (model YSI 550A) and pH Cyber Scan waterproof, respectively. Water temperature and pH were in the range of 27.5–28.8 °C and 5.6–7.3 respectively and was acceptable for African catfish.

Samples of *C. gariepinus* fingerlings, with an initial average body weight of 30–40 g were randomly transferred into three replicate fiberglass culture tanks. Water exited and flowed from the culture tank was sprinkled over the vegetables in the hydroponic trough and outflow trickled down to the sump for denitrification process. The components were installed such that the water flowed by gravity, by placing components at appropriate elevation relative to one another. The water was then pumped vertically to the sand filtration tanks for particulate removal. After exiting the sand filter the water went directly to water storage tank and was flowed by gravity back to the fish tank. During this study the inflow rates of the RAS were maintained to be identical as possible by adjusting the gate valves according to the target rate of each trial.

In the first experiment, five trials were consecutively performed at different hydraulic loading rates, each operating for 35 days and compared with control with no plants. Each treatment was replicated thrice. The experimental was operated with fish for one week prior to the initiation in order to acclimate the biofilters as to minimize net nutrient uptake by bacteria at the beginning of each trial. At the initiation of hydraulic loading rate of 0.64 m/day, system was flushed and fingerlings African catfish were added to each culture tank up to the treatment biomass. Due to our inability to obtain fish of similar size for trials two and three, fish from the prior trial were pooled and reallocated to the systems for the following trial. Hand feeding, twice per day at the range of 2–4% body weight/day. Fish were fed with 3.2 mm commercial diet floating pellet (Cargill Company) with 32% protein and 10% moisture. The food size was adjusted to compensate for changes in fish size. Water spinach seedlings were planted directly into the gravel substrate of the hydroponic growing bed at 10 cm × 10 cm spacing.

In the second experiment, the effect of seven ratios of plants to fish (2, 4, 6, 7, 8, 9 and 10) was evaluated by manipulating water spinach stocking rate. The size of the hydroponic trough and system volume were the same for all ratios, but the daily feeding rate increased in direct proportion to the fish biomass. African catfish were stocked into rearing tank as at optimum HLR obtained in the first experiment. Water samples from outlet of fish tank and outlet of the hydroponic trough were collected once a week for water quality determination. At the end of the experiment, all fishes in each tank will be netted, weighed and their individual lengths will be recorded as well as the weight of vegetable.

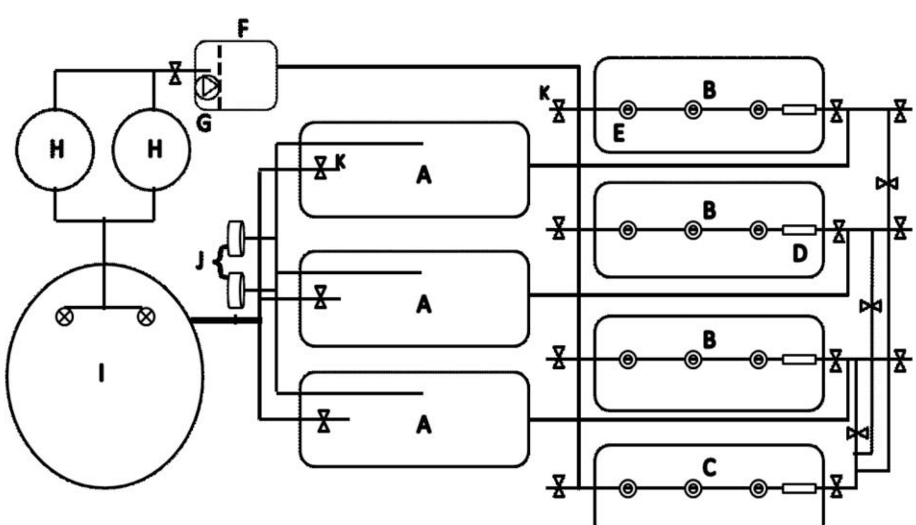

Fig. 1. A: Culture tank, B: hydroponic trough (planted bed), C: hydroponic trough (control bed), D: filter, E: sprinkler, F: sump, G: pump, H: rapid sand filter, I: water storage tank, J: air blower, and K: valves.