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Effects of feeding frequency and photoperiod on water quality and crop production in a tilapia–water spinach raft aquaponics system

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A B S T R A C T

A factorial arrangement of 6 treatments, 2 photoperiods for water spinach *Ipomoea aquatica* (12-h or 24-h light per day) X 3 feeding frequencies for red tilapia *Oreochromis* sp. (an equal daily ration evenly fed 6, 4 or 2 times at 4-h, 6-h or 12-h interval, respectively) were assigned to 12 tanks. Each tank was an aquaponics system containing fish and raft-supporting plant. Water loss in 4 weeks was 3.3%, due to leaf transpiration mainly and evaporation. Water quality remained safe and stable. No fish died. Overall average weight gain was 43.9% for fish and 169.0% for plant. 24-h light resulted in 2.4% higher fish growth, 12% higher plant growth and lower accumulation of all nitrogen and phosphate species in water than 12-h light. Increased feeding frequency favored stable and good water quality and fastened fish growth and plant growth by as much as 4.9% and 11%, respectively.

1. Introduction

Aquaculture is the culture of aquatic organisms, commonly referred as animals, in a designated water body. The water needs to be treated whenever toxicants in it have built up beyond animal's safe level. Toxicants such as ammonia and nitrite are derived from decomposition of unconsumed feed and metabolites or waste of the animals. Hydroponics is the culture of aquatic plants in soilless water where nutrients for plant's growth come entirely from a formulated fertilizer. Aquaponics (a portmanteau of the terms aquaculture and hydroponics) integrates aquaculture and hydroponics into a common closed-loop eco-culture where a symbiotic relationship is created in which water and nutrients are recirculated and reused, concomitantly fully utilized and conserved. In aquaponics system, waste organic matters from aquaculture system, which can become toxic to animals, are converted by microbes into soluble nutrients for the plants and simultaneously, hydroponics system has already treated the water and recirculates back to aquaculture system with cleansed and safe water for the animals. Besides its ecological merits, aquaponics system can obtain extra economic advantages: saving cost (input) on water treatment for aquaculture system, saving another cost on formulated fertilizer for hydroponics system and benefit from double outputs, harvest of animal and plant, by a single input, fish feed.

Tilapia is the most commonly used fish in aquaponics systems (Rakocy et al., 2006) for their high availability, fast growing, stress and diseases resistant and easy adaptation to indoor environment (Hussain, 2004). Water spinach or swamp cabbage *Ipomoea aquatica* is a semiaquatic tropical macrophyte and commonly grown as a leaf vegetable in East and Southeast Asia. It has hollow stems, rooting at the nodes and flourishes naturally in waterways or moist soil. It requires little care to grow and hence low cost and popular in Taiwan. It has been found effective in treating aquaculture waste water (Li and Li, 2009) and eutrophic water with undesirable levels of nitrogen and/or phosphorus (Hu et al., 2008). Nutrients dynamics are quite complex in aquaponics system (Seawright et al., 1998). In such system, feed is the primary source of nutrients which are eventually tied up as the biomass of animal, plant and microbes or stayed free in water. When no discharge, no nutrients are output until the animal and plant are harvested as economic crops. Through microbial decomposition, the insoluble fish metabolite and unconsumed feed are converted into soluble nutrients which then can be absorbed by plant. Therefore, plant growth and production are indirectly related to feeding strategies, fish metabolic condition and microbial activity. While plant removes the soluble nutrients, water

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is filtered. Consequently, water quality or safe guard of fish growth and production depends highly on the disposal capacity of the plant.

Besides the above factors which affect the nutrient availability for plant and fish, system designs, plant and fish species and other physical factors such as temperature, light sources and photoperiod all add up the managing complexity for a steady state of nutrient flow, which can be essential for the stable and predictable production of fish and plant in aquaponics system. Since photoperiod affects photosynthesis and plant growth, the increase of photoperiod may also increase the removal capacity of nutrients in aquatic macrophyte. Some studies have showed that the growth and productivity of floating aquatic macrophytes are directly related to the intensity and amount of light, so are the absorption rates for nutrients (Gopal, 1987; Urbanc-Bercic and Gaberscik, 1989). Petrucio and Esteves (2000) found that 2 h longer photoperiod a day enabled two aquatic macrophytes to reduce more nutrients from the water. Feeding frequency can affect feed intake of fish, quantity of uneaten feed, feed utilization efficiency and consequently, metabolite and excreta of fish and water quality. In an intensive culture of fingerling walleye *Stizostedion vitreum*, Phillips et al. (1998) found that higher frequency feeding resulted in higher daily dissolved oxygen (DO) and lower total ammonia nitrogen. Postlarval Ayu *Plecoglossus altivelis* with higher feeding frequency at lower feeding rate had higher survival and growth (Cho et al., 2003). When fed at 10% body weight daily, newly weaned Australian snapper *Pagrus auratus* fed 8 times a day had higher growth and lower size heterogeneity than fed 4 and 2 times a day (Tucker et al., 2006). Therefore, in the present study we investigate under a constant nutrient input, namely, the feeding rate, if increasing photoperiod can increase plant production, concomitantly, plant's filtering capacity and nutrient concentration in water and also if increasing feeding frequency can even out through time, fish metabolite and excrete, concomitantly, stabilize water quality and increase fish production.

2. Materials and methods

The experiment had a factorial arrangement of 6 treatments, namely, 3 feeding frequencies for red tilapia *Oreochromis* sp. X 2 photoperiods for water spinach *I. aquatica* Forsk. Illumination was 12 h or 24 h daily. An equal daily ration was evenly fed to the fish 2, 4 or 6 times at 12-h, 6-h and 4-h interval, respectively. Each treatment had 2 replicates or experimental units. The experiment was completed in 4 weeks.

Each experiment unit had an orange plastic tank (115 cm L × 102 cm W × 99 cm H), filled with 1000 L freshwater and stocked with 8 fish at 467 ± 30 g each or around 3.7 kg m^{-3}. Constant aeration was provided at tank bottom by a membrane disc diffuser (LTD-325/325 mm, Aquatek, Kaohsiung, Taiwan), which had a membrane diameter of 32.5 cm and provided an intensive air throughput of 0.02–0.12 CMM 1–3 mm diameter air bobbles. A piece of 3-cm thick polyethylene raft covered almost entire water surface except a 15 cm × 15 cm corner cut open, allowing an automatic feeder release pellet feed into the water. A cut plant stem 25.1 ± 3.7 cm or 7.8 ± 0.5 g was wrapped around with layers of sponge, stuffed in a black plastic ring (4.5-cm D) then fit into one of the 63 evenly distributed round holes. Total plant biomass on a raft was 490.2 ± 5.5 g. Part of a stem was submerged to expose its first bottom node, allowing for root initiation. A piece of coarse screen (2.54 cm mesh) was secured 20 cm below the polyethylene raft to prevent the plant root from possible disturbance by the fish. Each tank was encased in a 200-cm tall wooden framework, which a timer, a feeder and an illumination device could be fixed onto. A near-sunlight 28-W 115-cm T5 tube was used for illumination, hanging 25 cm above plant top and its height was adjusted as the plant grew. Top and sides of the framework were covered with black vinyl to obstruct the interference of illumination from outside.

Each day same ration of feed for all experimental units was hand loaded in the funnel of a feeder. Coupled with a timer, the feeder released feed 2, 4 or 6 times a day at 12 h, 6 h or 4 h interval, respectively, as designated in the experimental design. In this 4 week period, daily ration was gradually decreased from 5% to 3% fish biomass as fish grew. A commercial tilapia feed was used, which contained 25% crude protein, 3% crude fat, 12% crude ash, 6.5% crude fiber, 2% acid insoluble and 11% moisture. No water was added or exchanged throughout the experiment.

Water was sampled weekly and monitored for pH (HM-20P, DKK-TOA, Tokyo), dissolved DO and temperature (Oxi 330i, WTW GmbH, Weilheim, Germany) and electrical current (EC) (750II conductivity/TDS monitor, Myron L. Company, Carlsbad, CA). Total ammonia-N (TAN), nitrite-N, nitrate-N, total nitrogen, soluble phosphate-P, total phosphorus were analyzed by flow injection analyzer (FIA) (Flow Solution™ FS3100, O. I. Analytical, College Station, TX). The absorbance wavelengths used and methods based for the analysis of those substances were 640 nm and phenol hypochlorite method (Solorzano, 1969) for ammonia nitrogen, 543 nm and Pink azo dye method (APHA, 1992) for nitrite nitrogen, 543 nm and Cd–Cu reduction method (Bendschneider and Robinson, 1952; Strickland and Parsons, 1972; APHA, 1992) for nitrate nitrogen, 543 nm and Cd–Cu reduction method (Strickland and Parsons, 1972; APHA, 1992) by Grasshoff et al. (1983) for total nitrogen, 885 nm and molybdenum blue method (Strickland and Parsons, 1972) for phosphate and 885 nm and method by Grasshoff et al. (1983) and Strickland and Parsons (1972) for total phosphorus. Analysis of five days' Biochemical Oxygen Demand (BOD_5) was based by Sawyer et al. (2003). Biomass of fish and plant was measured at 0, 2 and 4 wk. In wk 2, plant 25 cm above the raft was cut, weighed and harvested. In wk 4, all fish and whole plant were harvested. Fish weight gain (%) was calculated as the ratio of average individual fish weight in wk 2 or wk 4 to average individual fish weight in wk 0. Plant weight gain (%) in wk 2 was calculated as the ratio of the biomass of cut part/initial biomass and plant weight gain (%) in wk 4 further added the ratio of the biomass of whole plant/initial biomass.

Three-way ANOVAs were performed to determine time effect, the effects of photoperiod and feeding frequency and their interaction on fish and plant growth and water parameters. Duncan's multiple range test (DMRT) was used to compare differences among levels of a factor. The significant level applied to all analyses was set to 5%. SAS version 9.0 software (SAS Institute, Inc., Cary, NC) was used for statistical analysis.

3. Results and discussion

3.1. System setup (Fig. 1)

Raft aquaponics can be the most simple and least cost aquaponics system. The essential elements of an aquaponic system as suggested by Rakocy et al. (2006) are fish-rearing tanks, a settleable and suspended solids removal component, a biofilter, a hydroponic component and a sump. In raft aquaponics if the plant and its supporting media such as gravel and coarse sand can provide sufficient biofiltration, a separate biofilter is not needed (Rakocy et al., 2006). Solids removal component is highly recommended by Rakocy et al. (2006) since if otherwise the organic materials from fish fecal waste and unconsumed feed accumulate, deposit and decompose anaerobically in tank bottom, the reduced toxic products can deteriorate water and harm the fish. In our system, the upwelling afloat from disk membrane diffuser kept the solids