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Optimization of hydraulic loading rate in aquaponic system with Common carp (*Cyprinus carpio*) and Mint (*Mentha arvensis*)

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ABSTRACT

Aquaponics is the combined culture of fish and plants in recirculating aquaculture systems, considered to be an innovative, eco-friendly and sustainable technology. The present study on bio-integration of Common carp and Mint in aquaponic system was aimed at determining the optimum hydraulic loading rate (HLR) for the aquaponic system. Three treatments having different HLRs *viz.*, T1 (3 m day^{-1}), T2 (6 m day^{-1}) and T3 (12 m day^{-1}) were compared and their effect on fish growth, survival, mint growth, yield and various water quality parameters were observed to find the most efficient HLR for Common carp and Mint in aquaponic system. Different HLRs showed significant effect on fish growth in terms of length and weight gain, survival, specific growth rate (SGR). Higher growth rate was observed in treatment T2 (6 m day^{-1}) as compared to other treatments and control having different HLRs. Mint growth rate at the end of both the harvests showed significant variation and got affected by different HLRs with better results obtained in treatment T2 (6 m day^{-1}). Overall water quality parameters, nutrient removal and biofilter performance were better at HLR 6 m day^{-1} i.e., treatment T2. Hence, HLR of 6 m day^{-1} can be recommended for culturing Common carp and Mint in aquaponic system.

1. Introduction

Aquaponics is the integration of aquaculture and hydroponic systems which is a promising sustainable food production method. Fishes are fed with complete diets and their excreta are broken down by bacteria into useful plants nutrients for normal growth of plants and the filtered water is returned back to the fish culture tank. Hu et al. (2012) believed that aquaponics will become one of the widely accepted methods of sustainable food production in the near future because of the current and escalating extent of soil degradation, water scarcity and climate-related challenges plaguing agricultural productivity in every corner of the world. And also no pesticides or antibiotics are used at any stage; therefore, the aquaponic production system can be regarded as a part of the organic agriculture (Rakocy, 1999). Recirculating aquaculture and hydroponics technology when integrated lessen the use of water resources and increases the productivity of the system by yielding fresh healthy fish and vegetables, fruits and herbs.

Water is essential for keeping all organisms alive in aquaponics. And thus its movement in the system and the rate of turnover should be designed to ensure good water quality. Water flow in the system should be optimized to be adequately filtered to make sure proper stripping off compounds/nutrients that are toxic to fish. Aquaponic system can be highly successful if it is balanced and managed correctly. A comparison of 3 different hydroponic sub-systems (gravel bed, floating and nutrient film technique) in an aquaponic test system was conducted by Lennard and Leonard (2006); and, the highest yield and biomass of *Lactuca sativa* was recorded in gravel bed system when compared with floating and NFT systems. According to that, gravel bed is more suitable for aquaponic when comparing the other hydroponic systems. Integrated systems use water more efficiently through the interacting activities of fish and plants. The addition of water to fish tank for 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. Correlation of water flow rates and hydraulic loading rate with production in an aquaponic system was identified by Endut et al. (2009, 2010), Dediu et al. (2012), Hussain et al. (2014) and Nuwansi et al. (2016) with using different fish and plant

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species, tested with different hydroponic systems. The objective of this study was to determine the optimum hydraulic loading rate for efficient working of the aquaponic in terms of fish yield, plant production and nutrient removal with Common carp as fish species and Mint as plant species in gravel bed hydroponic system.

2. Material and methods

The experiment was conducted for a period of 2 months at the wet laboratory unit of Aquaculture Division, Central Institute of Fisheries Education, Mumbai, India. Common carp (*Cyprinus carpio*) fry were procured from a commercial fish farm, Gujarat, India. They were acclimatized at the wet laboratory facility of the institute for another 25 days and fed on commercial pelleted diets containing 35% protein. Mint seed was procured from the Ratanshi Agro, Mumbai, India. Seeds were planted in coco-peat. After growing for 10 days, plantlets were thoroughly washed and transplanted into the aquaponic system. Completely randomized design (CRD) was followed for the experiment using three replicates for each treatment. The system was operated outdoor, under shade cloth.

One aquaponic unit (Fig. 1) consisted of 3 tanks namely fish tank, sump tank and hydroponics tank (For plants). Nine independent (not connected to each other) aquaponic units were maintained in this experiment as three treatments and 3 separate fish tanks without the hydroponic system used as control. Capacity of fish tank, sump tank and hydroponics tank were 500 l, 400 l and 1000 l respectively. Initial mean body weight and mean length 0.30 g, 2.13 cm of *C. carpio* was stocked in cylindrical tank (500 l) as fish culture. Fish biomass in every tank was 300 numbers m^{-3}. Water flow was maintained from fish tank to sump tank and then to hydroponics tank. A submersible water pump (capacity 50 l min^{-1}) was fitted into the sump tank which lifted water from sump to hydroponics tank. In hydroponics tank crushed stones (construction gravel) of 0.5–1.0 cm were used as the gravel bed and it was 30 cm in height and with the grow bed surface area of 2 m^2. A bell siphon was assembled in the hydroponics tank to maintain the flood and drain system which was connected to fish tank. Cyclic timer (Crouzet TMR 48 l) was used to control the water pumps. Timer was set to switch on the pumps for 10 min and off for 50 min every hour. The experimental design consisted of three treatments (Table 1), each having three randomly assigned replications against control in which fish were stocked in tank without aquaponics and were maintained with normal feeding and water exchange. Mint was grown in field condition (soil) as a control to compare with aquaponic system.

Hydraulic loading rate of a system is calculated by dividing the flow rate of water, Q (m^3 day^{-1}) through the system by the surface area of the grow bed, A (m^2) (Endut et al., 2010):

$$\text{HLR}\left(\text{m day}^{-1}\right) = \frac{Q}{A} \quad (1)$$

The fish fry were provided with artificial pelleted feed at 5% of body weight twice a day (at 10 h and 17 h), after every sampling weight was measured and the daily feed ration was adjusted accordingly. Sampling of fishes was carried out at 15 days interval for assessment of growth (length and weight). Growth parameters *viz*., weight gain percentage, specific growth rate (SGR), Feed conversion ratio (FCR), Feed efficiency ratio (FER) and Protein efficiency ratio (PER) were estimated. Sampling of plants was done by measuring height and yield of plants. Water quality parameters *viz*., temperature, pH, dissolved oxygen, free carbon dioxide, total hardness, alkalinity, ammonia, nitrite, nitrate, phosphorus, potassium, calcium, magnesium, sodium, iron and zinc were analysed during the experimental by weekly interval using the standard methods (APHA, 2005).

The data were subjected to analysis using statistical package SPSS version 16 in which one way ANOVA and Duncan's multiple range test were performed at significance level of ($p < 0.05$) at 95% confidence limit to know the significant difference between the treatment means for different parameters.

3. Results and discussion

3.1. Water quality parameters

Water temperature did not show any significant variation throughout the experimental period for the values of control and aquaponic treatment groups. It varied within a narrow range (25.0–26.5 °C). Water temperature is one of the important factors responsible for optimum fish growth, plant growth, and performance of nitrifying bacteria in biofilter. In the present study, water temperature was within the range of 25.0–26.5 °C which is acceptable for carp culture. The water pH during the study period varied within a range of 7.0–8.5, with no marked variation among the treatments at time of sampling. Different HLRs did not show any significant effect on water pH which was found in desirable limits for fish as well as plant growth and biofilter functioning. Colt (2006) showed that the basic pH increased NH_3 toxicity and acidic pH increased NO_2 toxicity. High and low pH levels also decrease nitrification process. Treatment T1 (3 m day^{-1}) showed significantly lower dissolved oxygen (DO) content than control and other treatments (T2 and T3). DO levels in the water showed relative increase with increasing HLRs. Because of enhanced water circulation in the system which subsequently increases the DO content. Optimum DO level is very much important for the recirculating systems as nitrification process stops at lower DO levels (Colt, 2006). Low DO concentration may interrupt the nitrification cycle and insufficient nitrate can directly impact the plant growth. Aggregation of NH_3 and NO_2 may rapidly increase the water toxicity due to low DO concentration. Free carbon dioxide concentration in the water showed inverse relationship with HLRs. Carbon dioxide (CO_2) concentrations can be formed in water as a result of respiration of fish, bacteria and plant roots in aquaponic system. The free CO_2 released during respiration reacts with water producing carbonic acid (H_2CO_3), and thus, pH getting decreased. Carbon dioxide rarely causes direct toxicity to fish. However, high concentrations lower the water pH and limit the capacity of fish blood to carry oxygen by lowering blood pH at the gills (Wurts and Durborow, 1992). According to Losordo et al. (1998), carbon dioxide concentration in the water is not highly toxic to fish when sufficient dissolved oxygen is present. However, for most species, free carbon dioxide concentration should be maintained below 3 mg l^{-1} in culture tank for good growth of fish. Total hardness of water in Treatment T1 and T3 was significantly higher than T2 and control. Total alkalinity of water in control was significantly lower than the aquaponic treatment groups (Table 2). Total alkalinity and total hardness of the water varied within narrow range and they were found within optimum limits for the fish as well as plant culture. In most waters, the bases are principally bicarbonate and carbonate ions. These ions act as

Table 1
Water flow rate and hydraulic loading rate in different treatments.

Treatment	Water flow rate (l h^{-1})	Water flow rate "Q" (m^3 day^{-1})	Hydraulic loading rate "HLR" (m day^{-1})
T1	250	6	3
T2	500	12	6
T3	1000	24	12