Nutrient Recovery from Fish Farming Wastewater: An Aquaponics System for Plant and Fish Integration

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Abstract: Population of Bangladesh is increasing in geometric scale that creates pressure on natural resources and food security, hence, increasing demand of fish protein. For this farmers use a huge amount of water, feed and chemicals which depleted underground water, creates air and water pollution and hazards on environment as well as on human health. An attempt made to introduce aquaponics system for fish and vegetable production through deceiving aquaculture wastes. The aquaponics systems such as media based system for taro and tomato and nutrient film technique for water spinach used to see the effectiveness of nutrient trapping and vegetable grown in lab and field conditions. Tilapia was the experimental fish in all the systems for its hardy nature. Fishes fed pellet feed twice at 10% gradually it is decreased at 5% of their body weight. Fish tank water irrigated with a mini pump to the systems which then return to the fish tank. The denitrifying bacteria convert the wastes into nutrients for the vegetables and made the water clean for fish before return to the tank again. All the experiments gave better performance than the control. The tomato production cycle in aquaponics system was longer and less disease prone than the control. Farmers of experiment area accept this technique willingly and their perception on aquaponics performances is good. The experiments showed that nutrient recycling is not a luxury reserved for rural areas with space limitation; instead, the additionally occupied surface generates income by producing marketable goods. By converting nutrients into biomass, treating wastewater could become a profitable business in third world countries.

Key words: Irrigation · Tilapia · Environment · Pollution · Vegetable

INTRODUCTION

Aquaponics is an innovative and alternative food production technique that integrates traditional methods of aquaculture and hydroponics to grow both fish and crops in a single integrated system. Aquaponics system uses fish wastes to provide essential nutrients to the plants. In return plants serve as a bio-filter for the fish in a symbiotic relationship. The hybrid nature of the system reduces maintenance and inputs cost while yielding equal or higher amounts of fish and crops than aquaculture and hydroponic alone [1-3]. Land gets shrinking, uncontrolled population growth and complex and unpredictable weather creates new challenges to the country’s agriculture that highlighted the developing new crop production system like aquaponics. Aquaponics technique is one of the valuable ways of using aquaculture site for the production of vegetables also and that may help to overcome the increasing nutrition demand of Bangladesh [4]. It has control on farming systems which can protect the crops from diseases, heavy rains, floods, drought and hailstones. The aquaponics is an environmental friendly and sustainable food production system [5]. In aquaponics system tilapia was used as experimental fish because they have good resistance to poor water quality and disease, tolerance of a wide range of environmental conditions and rapid growth rate and tasty flavor [6]. Therefore, an attempt made to see whether aquaponics is capable to trap the nutrients from aquaculture wastewater before releasing into the nature and reduce adverse environmental impacts.

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MATERIALS AND METHODS

Three separated experiments were carried out using the recirculating aquaculture system (RAS) at the Department of Aquaculture, Bangladesh Agricultural University lab and field at Dacope upazila, Khulna district in southwestern coastal region of Bangladesh. Two plastic water tanks (750 liter) used for fish rearing in lab and other fifteen tanks used in the field. The tanks oxygenated individually with a 12 watt two ports aquarium air pump. Three plastic half drum used (110 L capacity; height 0.32 m, long 1.0 m, diameter 0.56 m) for growing taro in lab and forty-five baby plastic bath tubs (110 L capacity; height 0.30 m, long 1.0 m, diameter 0.57 m) used for tomato culture in the field in media based system. A six meter long and 10 cm diameter plastic pipe cut in to three equal pieces, made seven holes in each pipe in equal distance to hold the perforated plastic cup with brick lets to seedlings the water spinach. Twenty days old taro, tomato and water spinach sapling planted in the experiments with three replicates to produce taro and tomato and seven replicates in spinach. The flow rates of the systems were 30 L h⁻¹. Each tank covered with a plastic square lid to avoid fish to jumping out and reduced evaporation water losses. Mono sex tilapia fingerlings collected from local hatchery and acclimatized with the fish tank water prior to release in the system. Stocking size of tilapia were 7.70±0.89 cm and 6.18±0.92 cm and 5.85±2.30 cm and 9.06±1.22 cm and 17.27±6.50 g respectively, for taro, tomato and water spinach production. The fish fed pellet feed at 5% of their body weight twice daily, at 9:30 AM and 5:00 PM. Water loss due to evaporation and system loss adjusted regularly to keep the water in constant height. Water quality parameters, nutrients removal, fish growth, fish condition factor, fish production, taro, tomato and water spinach growth monitored fortnightly.

Fish production, plant growth and nutrients exclusion determined and expressed as mean ± (Standard deviation). Data analyses performed using Microsoft Excel, with an alpha set at 0.05 (Significance at P<0.05). Mean values of fish production performances, crop growth rate, crop yield and nutrient removal tested with two-way ANOVA. If there were significant differences at significant level 0.05, then Duncan multiple comparison test used to compare means to show significant difference between the treatments.

RESULTS

Water Quality Parameters: Water quality parameters for taro, tomato and water spinach RAS were similar except temperature in tomato RAS (Fig. 1). The temperature in tomato RAS was significantly different from the other two aquaponic systems because the experiment was in open field. Slight fluctuation of Dissolved oxygen observed but not significantly different among the experiments. However, variation of pH was less and there were no significant differences among the experiments.

The nutrient removal by taro, tomato and water spinach RAS showed in the Fig. 2 and Fig. 3. The highest mean reductions of ammonium-N, nitrite-N, nitrate-N and phosphate, respectively were found in water spinach RAS followed by taro and tomato RAS. These removals were significantly difference in percent removal among the water spinach, taro and tomato RAS at 5% significant level (P<0.05). The highest amount of phosphate removed in all the three RAS followed by nitrate-N, nitrite-N and ammonium-N (Fig. 3).

Differences in specific nutrient contents during the trial in three RAS (Taro, tomato and water spinach RAS) shown in Fig. 2. The nutrient concentrations increased with the progress of culture time in the influent and average accumulation were 0.37, 0.36 and 0.41 mg/L of ammonium-N respectively in taro, tomato and water spinach RAS. The highest accumulation was with water spinach RAS (0.59 mg/L) followed by 0.49 mg/L in tomato RAS and the least amount accumulated in taro RAS (0.47 mg/L). The variations of nitrate-N concentrations over 115 days culture period in three RAS shown in Fig. 2c.

Fish Growth and Yield: The growth of tilapia in different experiments in weight gain, length gain, % length gain, % weight gain, daily growth rate, survival (%) and production (kg/tank/115 days) calculated (Table 1). Tilapia production was 7.55±0.02, 7.75±0.02 and 10.65±0.06 kg in 115 days in taro, tomato and water spinach RAS replication. There were no significant differences of fish production between taro and tomato RAS but fish production in water spinach RAS was significantly higher than the other two systems. Length-weight statistics obtained for each experiment given along with the estimated length-weight relationship and coefficient of determination r² values were 0.97, 0.95 and 0.98 respectively for taro, tomato and water spinach RAS.
Table 1: The growth parameters of tilapia in taro, tomato and water spinach RAS in lab and in field condition

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Taro Exp</th>
<th>Tomato Exp</th>
<th>Spinach Exp</th>
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<tbody>
<tr>
<td>Water flow rate (l/min)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Duration of culture</td>
<td>115</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Initial stocking density (kg/m²)</td>
<td>1.65±0.01</td>
<td>0.80±0.01</td>
<td>2.3±0.01</td>
</tr>
<tr>
<td>Mean initial length (cm)</td>
<td>7.70±0.90</td>
<td>6.18±0.92</td>
<td>9.06±1.22</td>
</tr>
<tr>
<td>Mean final length (cm)</td>
<td>16.76±0.80</td>
<td>16.60±1.18</td>
<td>18.92±1.37</td>
</tr>
<tr>
<td>Mean length gain (cm)</td>
<td>9.06±0.66</td>
<td>10.42±1.11</td>
<td>9.86±2.03</td>
</tr>
<tr>
<td>% length gain</td>
<td>219.57±19.89</td>
<td>272.70±35.98</td>
<td>212.91±36.33</td>
</tr>
<tr>
<td>Mean initial weight (g)</td>
<td>12.39±3.69</td>
<td>5.85±2.30</td>
<td>17.27±6.50</td>
</tr>
<tr>
<td>Mean final weight (g)</td>
<td>96.09±13.86</td>
<td>92.11±18.60</td>
<td>133.13±26.57</td>
</tr>
<tr>
<td>Mean weight gain (g)</td>
<td>83.70±12.92</td>
<td>86.26±17.40</td>
<td>115.86±29.56</td>
</tr>
<tr>
<td>% weight gain</td>
<td>828.95±283.83</td>
<td>1754.3±635.62</td>
<td>926.18±481.94</td>
</tr>
<tr>
<td>Daily growth rate (g)</td>
<td>0.98</td>
<td>0.76</td>
<td>0.74</td>
</tr>
<tr>
<td>Survival rate (%)</td>
<td>90.2±14.67</td>
<td>89.8±0.92</td>
<td>91.90±1.91</td>
</tr>
<tr>
<td>Production (kg/tank/cycle)</td>
<td>7.55±0.02</td>
<td>7.75±0.02</td>
<td>10.65±0.06</td>
</tr>
</tbody>
</table>

Fig. 1: pH, Dissolved oxygen and water temperature in taro, tomato and water spinach RAS experiment in lab and field condition

Fig. 2: The fluctuation of effluents density in RAS with the time passes showed in (2a) ammonium-N, (2b) nitrite-N, (2c) nitrate-N and (2d) phosphate
Fig. 3: Comparison of nutrients removal percent from all three RAS

Fig. 4: Regression analysis of fish length and weight showed linear relationship in taro, tomato and water spinach RAS (Fig. 3). Conversely the correlation coefficient (r) was 0.99, 0.97 and 0.98 respectively for taro, tomato and water spinach RAS. Linear regression were significant for all the treatments (P<0.05) (Fig. 4).

DISCUSSION

Aquaponics system represent aquatic environment like a natural ecosystem which combined of plants, gravels, bacteria, substrates and water flow to enhance physical, chemical and bacteriological procedure naturally available in the root zone of the plants.

The removal of nutrients was also significantly different in all the systems. Organic nutrients removal is possible as special features of plants, such as taro, water spinach and tomato, which transfer significant amounts of oxygen from air via their root networks. Furthermore, roots provided the surface for growth of microbial populations that is the key task of the plants in aquaponics system. Endut [7] and Rakocy [8] found that these are essential for breakdown the compounds, such as ammonia to nitrite and nitrite to nitrate-the first step of organic removal of the compound. All the concentration was well below the tolerance level of tilapia [9, 10]. The nitrate-N concentration in fish tank water decreased in all the RAS but the reduction was fast in water spinach RAS than taro and tomato RAS. The removal was 67.33% at second fortnight which finally reached at 80.69% at the eight fortinights. Vaillant [11] reported that the nitrate-N removal was greatly influenced by water spinach as its root networks facilitated to harbour the Nitrobacter. Likewise it consumed by microorganisms in the water environment associated with the root mass of plants [12].

Significant decreased of ammonium-N, nitrite-N, nitrate-N and phosphate was constantly detected and change was similar for all the RAS. The effluents density was gradually increased with time (Fig. 2a, 2b, 2c and 2d). But, the nutrients density was gradually reduced towards the end of the experiment. Significant decreased in ammonium-N, nitrite-N, nitrate-N and phosphate in was constantly perceived and the pattern of changes in ammonium-N, nitrite-N, nitrate-N and phosphate shown in Fig. 3. The differences in effluent density of ammonium-N, nitrite-N, nitrate-N and phosphate among the three treatments were highly significant (P<0.05). Though the nutrient concentrations increased with the time, but it was within the tolerance level of tilapia [9,10].

In natural waters, ammonium-N converted by aerobic bacteria (Nitrosomonas) quickly to nitrite and further to nitrate by Nitrobacter, via nitrification. Both in lab and field continuous aeration provided to facilitated nitrification during the experiment. The ideal pH range for conversion ammonium-N to nitrite-N is 5.8-8.5 [13,14]. The pH was within the suitable range in all the present experiments. The nitrite-N range in the effluent was from 0.02-0.05 mg/L in all RAS (Fig. 2b). Ammonium-N and nitrite-N concentration less than 2 mg/L and 5 mg/L are good for tilapia culture [15]. Therefore, the effluents from taro, tomato and water spinach RAS were suitable for reuse in tilapia tank as all the concentration was well below the tolerance level of tilapia [9,10].
Growth of tilapia indicated that the growth rate varied in different experiments. The taro RAS showed significantly highest daily growth rate but highest survival obtained with the water spinach RAS among all the experiments. On the other hand percent length and weight gain was significantly different in all the experiments. The correlation coefficient in these experiments indicated that there were high degree of correlation between total length and body weight as it is close to 1 and its positive appearance reflected the positive slope [16]. The length weight relationship was statistically significant at 95% confidence level which was representative for the population. The condition factor of tilapia was 2.04, 2.16 and 1.96 respectively for taro, tomato and water spinach RAS. The condition factors K was higher than 1 in all RAS. Since the condition factor was larger than 1, it concluded that fish reared in tanks were in good condition as well as healthy. Condition factor for tilapia ranged between 1.66 to 2.02 and 1.64 to 2.13 which is similar with the present aquaponics study [17].

The growth of taro, tomato and water spinach is in RAS to measure the efficiency of aquaponics systems. The average crop yields at harvest after 115 days ranged from 4.65, 4.46 and 2.45 kg/ half drum for taro, tomato and water spinach RAS, respectively. Similar result reported with water spinach production by Savidov et al. [1].

CONCLUSION

The taro, tomato and water spinach are capable to cut water pollution from aquaculture wastewater. The three types of plants have different root structures and ability to uptake the nutrients from the wastewater. Although various types of vegetable used in this study which have to see the performances of RAS but crops did not affect fish growth, fish production and survival rate. This study indicated that fish effluents can supplement for organic fertilizers of vegetables production without affecting fish production. The recirculatory aquaponics system proved that it is not only a successful method for food crops production, but also a beneficial system to reuse aquaculture wastewater and safeguard the water resources of the country.

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REFERENCES