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ORIGINAL ARTICLE

Aquaponics Recirculation System: A Sustainable Food Source for the Future Water Conserves and Resources

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Abstract

The current and escalating extent of soil degradation, water scarcity and environmental concern plaguing agricultural productivity, demands re-assessing the direction of food production. Aquaponics is a concept relatively new to modern food production methods and can contribute to food security. This study was conducted to establish sustainable aquaculture systems that maximize benefits and minimize the accumulation of detrimental compounds and other types of negative impacts on both natural and social environments. This study carried out at an average inflow rate of 1.28 m/day to evaluate the operation of the aquaponics recirculation system (ARS) on nutrients removal and growth and yield of African catfish as well as water spinach. A special design of ARS was used to provide nitrification of fishery wastewater, where the combination of sands and gravels in hydroponics trough, providing both surfaces for biofuel development and cultivation area for plants. Removal efficiencies of 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), total ammonia nitrogen (TAN), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), and orthophosphate (PO_4^{3-}) were 82%, 89%, 93%, 94%, 81%, and 80%, respectively. The feed conversion ratio (FCR) and specific growth rate (SGR) of African catfish were 1.08 and 3.34% day^{-1}, respectively. The average water spinach production was 3.56 kg per m^2. This study showed that ARS is a method of producing crop along with a healthy protein source and among the best alternatives for achieving economic and environmental sustainability.

Keywords: African catfish; aquaponics recirculation system; food security; hydroponics; water spinach

Introduction

Aquaculture has traditionally played a role in ensuring food security for humans and is often a component of rural development programs to alleviate poverty. Aquaculture is the world's fastest-growing food-producing sector and to outpace world population growth rate of 1.6 %. It is estimated that aquaculture would account for 62% of world's fish supply for human consumption by 2030 (Food and Agriculture Organization of the United Nations, 2014). However, the large-scale application of aquaculture is restricted by land and water utilization as well as by environmental concerns (Islam, 2005; Schwitzguebel and Wang, 2007). As farming becomes more intensive, develops into efficient production units and profit oriented; land, water, and genetic resources will become endangered. In the absence of substantial inventions and advances in management and technology, production at these points will contribute to significantly increased pressure on the environment. Although the production systems may differ from region to region, depending the type of species cultured and related environmental factors, all forms of aquaculture involve utilization of natural resources and manipulation of biological organizations. It requires the utilization of resources such as fresh water and vast tracks of solid ground, feed materials and plant foods to create suitable products with simultaneous output of organic wastes and chemicals. This organic waste, which is an inevitable result of aquaculture activity, would not be harmful as long as its freight into the environment can be treated and recycled efficiently into the ecological food chain. Problems arise when aquaculture practices do not address concerns to minimize organic wastes to suit the environmental carrying capacityand refrain from using harmful chemicals and introduction of untested exotic species. As the human population increases, there is greater competition from domestic, industrial and agricultural users for fresh water supplies. There has been a large push toward more sustainable farming practices in an effort to feed more people with increasing efficiency while reducing the impact on the environment. Studies show that small-scale agriculture contributes significantly to household income and gives families access to inexpensive food, consequently reducing poverty (Hampwaye et al., 2009). The increasing demand for novel food production has created more demand for fresh water for irrigation. By using aquaculture wastewater for fresh food production, the nutrients available in aquaculture wastewater could be a beneficial use of plant growth (Menegaki et al., 2007). In order to feed the world’s growing population, there will be a great need for highly productive, urban and sustainable food production systems (Nelson, 2008).

Thus, the further expansion of aquaculture now depends on development and application of new technologies to intensify fish cultivation while maximizing water and nutrients reuse, and minimizing environmental impacts. Aquaponics, which is an integrated system that links recirculating aquaculture with hydroponic production, is considered to be an innovative and sustainable solution (Tyson et al., 2011). A well-managed aquaponics could improve nutrient retention efficiency, reduce water usage and waste discharge to the environment, and improve profitability by simultaneously producing two cash crops (Diver, 2006; Rakocy et al., 2006; Tyson et al., 2011). It is generally believed that aquaponics, with concomitant nutrients recovery, will become one of the widely accepted methods of sustainable food production in the near future (Hu et al., 2012). The advantage of aquaponics is its high nitrogen utilization efficiency. Nitrogen is an important element for all living organisms and protein-rich fish feed which is the major source of nitrogen for fish cultivation, representing 50–70% of fish production costs (Valente et al., 2011). In aquaculture system, it is estimated that about 30-65% of feed nitrogen and up to 40% of feed phosphorous is excreted (Schneider et al., 2005).

The technology associated with aquaponics is complex. It involves the power to manage simultaneous the production and selling of two different agricultural products. Modern aquaponics systems can be extremely successful, but they need intensive management and they have extra considerations. Nevertheless, information on using aquaponics for treating recirculating aquaculture water under low flow rate has not yet been extensively studied. In this study, hydroponic troughs planted with water spinach (*Ipomoea aquatica*) were integrated with an indoor recirculating aquaculture tank with a limited water exchange to regulate the water quality for intensive culture of African catfish (*Clarias gariepinus*). Fish and plant productivities and percent nutrient reduction were examined in this study. The need for the study arises due to the rising requirement for food and environmentally safe removal of contaminants due to aquaculture wastewater. From the presented data, it can be seen that aquaponics technology provided many advantages, both in term of environmental protection and food productions as well as profitability to the business. This provides an eco-friendly as well as a sustainable system for the agricultural sector.

Materials and Methods

Experimental Facility

The ARS utilized in this experiment is depicted in Fig. 1. ARS consisted of three fiberglass rearing tanks and three hydroponics troughs, allowing replication of experimental treatments, sand filter for solid removal, sump, water holding tank and reservoir tank. Pipelines made of polyvinyl chloride were installed to connect each component to the system for the purpose of water recirculation.

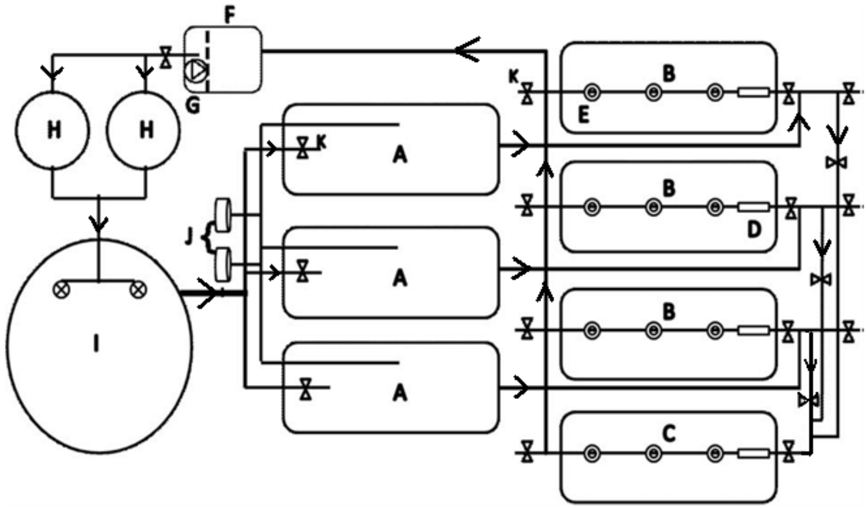

Figure 1. Top view of ARS. A: Culture tank, B: hydroponics trough (planted bed), C: hydroponics trough (control bed), D: filter, E: sprinkler, F: sump, G: pump, H: rapid sand filter, I: water storage tank, J: air blower, and K: valves.

The water drained out and flowed from the culture tank was sprinkled over the vegetables in the hydroponics 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 the appropriate elevation relative to one another. The water was then pumped vertically to the sand filtration tanks for particulate removal. After leaving the sand filter the water went straight off to water storage tank and was continuously flowed under gravitational force to fish culture tank through the water spreader bar.

Experimental Procedure

Sixty African catfish (*Clarias gariepinus*) juveniles with an initial mean weight of 30.6 g, were stocked in the system to generate the wastes for the evaluation. Prior to the commencement of experiment, fish were acclimatized for a week. The fish were hand-fed with 3.2 mm commercial diet floating pellets (32% protein content) in the range of 2-5% of body weight per day to apparent satiation twice daily, between 09.00 and 17.00 hours. The entire amount of feed eaten by the fish between each sampling period was measured by weighing the daily feed given. The feed rate was adjusted accordingly to the changes of fish sizes. With this regime, fish were expected to reach a market size of 220 – 250 g at 11 weeks. During the experiment, the culture tanks were uniformly aerated with air stones. All leftover feed, wastes, and dead fish in each tank were removed and recorded. The water flowed by gravity to the hydroponics trough, which was planted with water spinach. Water hydraulic loading rate (HLR) was set at a rate of 1.28 m/day.

At the end of the experiment, both fish biomass and plant biomass were determined by wet weight. The experiment was conducted in triplicate and one trough was used as a control and contained gravel only. The study was carried out in a newly built insulated greenhouse, in which environmental conditions were recorded but not controlled and the only natural light was used during the period of study.

Measurement of Growth and Water Sampling

The key variables of interest in this study are plant growth, and yield, fish growth and production as well as water quality parameters in recirculation systems. To evaluate the overall system functioning, data on fish development and feeding were recorded. A monitoring program of the aquaponics recirculation system began one week after planting in order to allow the vegetation and bio-film to be established. The feeding data recorded include the feeding rate, an amount of feed, the number of feeding/day, feed amount per day, and total feed per day. Fish food input and mortality data were recorded daily. Satiation feeding was employed on the first day of each sampling period for adjusting the amount of food offered to the percent of body weight per day. A representative of 20% of fish samples randomly selected per tank was weighted once a week in order to estimate the growth rate of fish. Fish sampling was done on a weekly basis for growth performances and average weight. However, plants growth was monitored twice a week by measuring the height of 20% plant samples. The weight gain in fish biomass was determined by the difference between initial and final biomasses on a per tank basis, whilst plant biomass was determined on an individual, per plant basis as well as per growing area. The plants were harvested at the final height ranging from 45 to 50 cm. Each growing trough was cleaned and the biomass of plants was measured and recorded. The following production parameters were determined according to the procedure of Ridha and Cruz (2001);

$$SGR = \left(\left(\ln\left(\frac{W_{t+\Delta t}}{W_t} \right) \right) \Big/ \Delta t \right) \times 100\% \tag{1}$$

where $W_t(g)$ is mean fish weight at sampling time *t.*

The SGR value depends on the average fish weight, W. The general form of the equation is $SGR = aW^b$ where a and b are constants; consequently at $\Delta t = 1$;

$$W_{t+1} = W_t \exp\left(SGR/100\%\right) \tag{2}$$

This general relationship was used to evaluate the average fish weight on any day based on the average fish weight on the previous day. The parameters a and b were determined by a logarithmic regression analysis between SGR and W.

Feed efficiency or utilization was expressed as feed conversion ratio (FCR). They were calculated using the following equations;

$$\text{Feed conversion ratio}\left(\text{FCR}\right) = \frac{\text{total weight of dry feed given}\left(\text{g}\right)}{\text{total wet weight gain}\left(\text{g}\right)} \tag{3}$$

Thereafter, weekly water quality analysis was performed on both the influent and effluent water from the treatment system. For the purposes of this study "influent water" refers to that which flowed from the fish culture tank to the treatment troughs, and "effluent water" to that which flowed out from the treatment troughs. Water samples were analyzed for biochemical oxygen demand (BOD_5), total suspended solid (TSS), total ammonia-nitrogen (TAN), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), and orthophosphate (PO_4^{3-}). On top of that, dissolved oxygen (DO), pH, and temperature in the sampling locations were also monitored. Weekly sampling was carried out between 9.30 am and 10.30 am in each sampling date and then stored in the refrigerator at 4^0C in labeled polythene bottles for further chemical analyses if the water samples could not analyzed immediately. The BOD_5 and TSS analyses were performed according to Standard Method (American Public Health Association, 2007). The TAN, NO_2-N, NO_3-N and PO_4^{3-} measurements were performed using HACH DR4000 spectrophotometer according to Nessler, diazotization, cadmium reduction and ascorbic acid methods, respectively. Removal efficiency were calculated for the above variables using the following equation;

$$\text{Removal Efficiency}(\%) = \frac{[\text{influent}] - [\text{effluent}]}{[\text{influent}]} \times 100\% \quad (4)$$

Measurements of temperature, DO, and pH of water samples were performed *in-situ* during the sampling process using the YSI multi-probe meter and pH Cyber Scan waterproof, respectively.

Results and Discussion

Plants Growth and Yield

After three days, the radicles of water spinach (*Ipomoea aquatica)* had broken through the seed coat and were visible on 70 – 80% of the seeds. Result of plants growth in terms of plant height and growth rate is shown in Fig. 2.

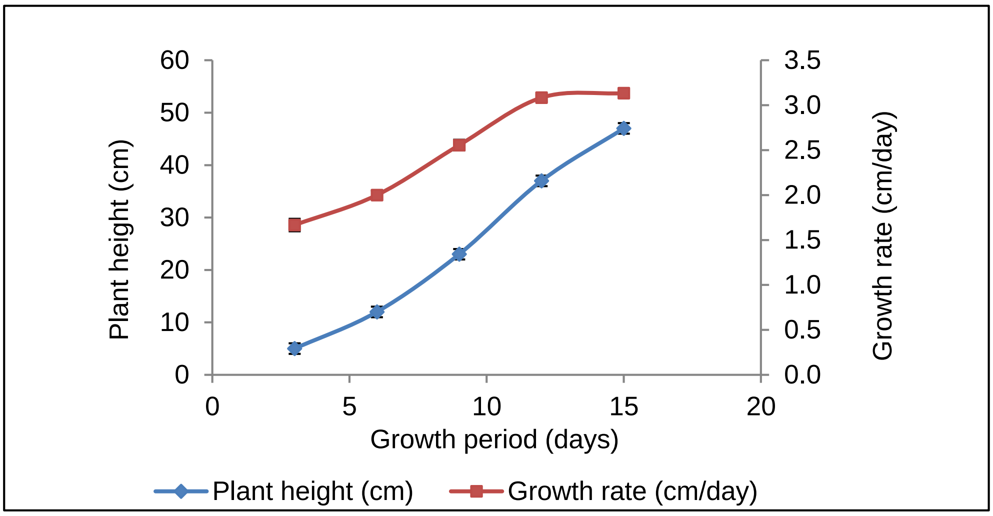

Figure 2. Plants growth rate during experimental period

During the germination period, the plant seedlings in all growing troughs grew rapidly and fairly uniform and appeared healthy with green in color. At the end of the germination period, the water spinach plants were approximately 4.0 cm height. The plants continued to grow rapidly and showed the same positive response to wastewater applications. The plants in all replicates grew quickly and seemed healthy, with no signs of any nutrient deficiency syndromes or toxic effect during the growth period. At the end of the growth period, the water spinach plants reached the market size of 45–50 cm.

Fish Production Performances

The fish growth was monitored weekly through fish sampling. The result shows that the average weight (AW) of fish increased with increasing growth period as shown in Fig. 3.

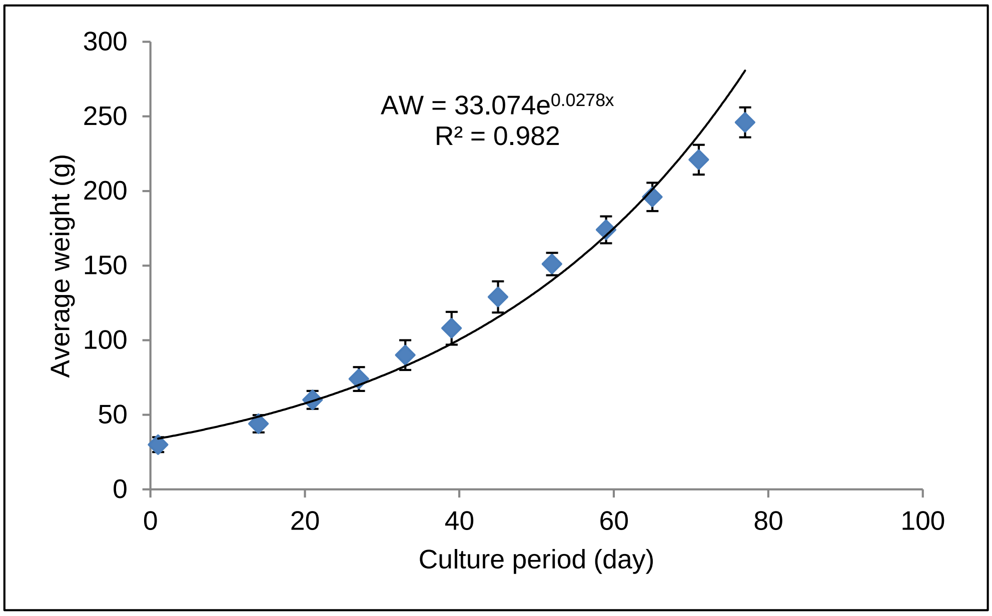

Figure 3. Growth curve of fish during experimental period

Corresponding to this growth curve, the equation of fish growth at time *t* is as in (5);

$$AW = 33.07e^{0.0278t} \tag{5}$$

It is known from the growth curve that it will take 70 days for the fish to grow from 32 g to 230 g, *i.e.* the smallest average fish in this experiment and the market size weight of fish. The growth curve did not occur under linear conditions especially regarding oxygen saturation and increased the density of the fish in tanks.

FCR were in the range of 1.08 and 1.12. Hu et al. (2015) reported an FCR range of 1.6 -2.0, therefore, the FCR values obtained in this study are better than and comparable with other research results using industry standard recirculation culture method. In the present study, fish mortality was less than 6%. Akinwole and Faturoti (2007) obtained mortality rate in the range of 13-23% for African catfish about 12 g in weight cultured at different stocking densities. The mortality in the present study was expected for African catfish of this size (30–100 g) in standard recirculation aquaculture. Mortality would be due to the natural death and to the manipulations during the weekly samplings. The present study revealed a relatively higher performance in fish production parameters compared to previous study (Akinwole and Faturoti, 2007) due to the high-quality fingerling provided and good water quality in the aquaponics recirculation system.

A significant correlation ($P < 0.05$; $R^2 = 0.973$) was found between the specific growth rate (*SGR*) of African catfish and fish weight, at the range of the temperature between 25 -

28°C. The correlation of *SGR* and fish weight is shown in Fig. 4 and equations of this correlation are expressed in (6) and (7), respectively;

$$SGR = 60.18 \times W_t^{-0.64} \tag{6}$$

$$W_{t+1} = W_t \exp\left[\left(\frac{\left(60.18 \times W_t^{-0.64}\right)}{100}\right)\right] \tag{7}$$

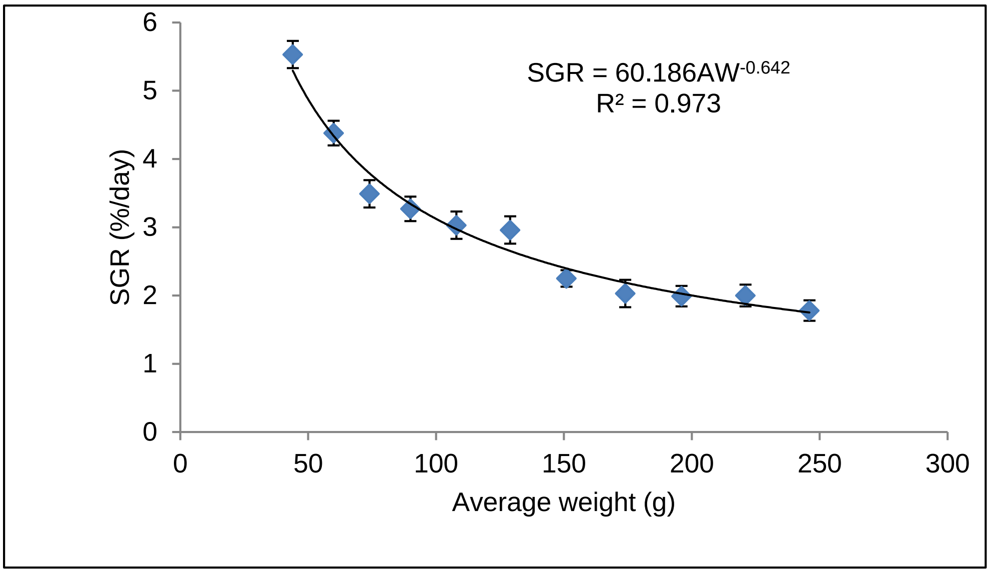

Figure 4. Correlation of specific growth rate and average fish weight

It was shown that the growth rate of fish of the early period was higher than that of the later periods. The factors influence the growth of fish was diet and fish size. The most important reason for the fast growth in the early period is the fact that fishes were starving for several days prior to the start of the experiment and food consumption was therefore much greater than usual intake. After this period, the increase of weight was more or less linear. The growth rate slowed when the fish had adapted to the new environment. Another reason of this reduction was due to the decrease in dissolved oxygen and higher stocking density in culture tank. For the fish growth sub-relationship, Pagand et al. (2000), found that $SGR = 13.90 x W_t^{-0.61}$ for sea bass reared in recirculation water system. The use of this relationship, together with a constant temperature that is generally used in recirculation rearing systems, provided simulations that fit with these observations. In this system, the fish growth rate was higher when fish average weight is below 90 g and lower fish growth rate when fish average weight is above 90 g.

Effluent Treatment System Performance

Results of nutrients percent removal are summarized and presented in Table 1. The values were the average of three replicate measurements. The levels of all nutrients were lower in the effluent water for both treatment systems.

The 5-day biological oxygen demand (BOD_5) concentration in the system increased with time during the germination period due to the release of dissolved and suspended organic matters from the developing seeds (Nelson, 2004). BOD_5 in influent averaged 5.5 mg/L and was reduced to 0.98 mg/L in effluent planted trough resulting in an average reduction efficiency of 82.18%. Lin et al. (2005) evaluated the use of Cattail (*Typha angustifolia*) and common reed (*Phragmites australis*) from aquaculture system stocked with shrimp and reported BOD_5 removal efficiencies of 37% and 54% for water flow rate of 42.7 m^3/day and 53.9 m^3/day, respectively. One of the mechanisms responsible for the removal of BOD_5 from the wastewater was the decomposition of soluble organic carbon by microbial communities. In aquatic, plant-based treatment systems, submerged plant parts (root zone) were typically covered with active biofilm. According to Bouzoun et al. (1982), plant root density and root surface area were major factors in BOD_5 removal. The greater the root surface area per unit volume of the tray, the higher the removal of BOD_5 because the greater surface area of the finer root system provides more sites for microbial growth. Another mechanism for the reduction in BOD_5 was the filtration of suspended particles by plant root mats and absorption of dissolved nutrients by plant roots (Brix, 1997).

Table 1. Percent removal of selected water quality parameters for control and planted treatments (mean ± standard deviation)

Parameter	Treatment type	Mean influent (mg/L)	Mean effluent (mg/L)	Mean percent removal (%)
BOD_5	W. spinach	5.50 ± 0.89	0.98 ± 0.10	82.18
	Control	5.50 ± 0.70	2.97 ± 0.31	46.36
TSS	W. spinach	73.33 ± 3.51	8.10 ± 0.66	88.95
	Control	73.33 ± 1.53	32.2 ± 2.03	56.09
TAN	W. spinach	0.83 ± 0.15	0.06 ± 0.02	92.77
	Control	0.83 ± 0.25	0.43 ± 0.07	48.19
NO_2-N	W. spinach	0.16 ± 0.04	0.01 ± 0.00	93.75
	Control	0.16 ± 0.03	0.08 ± 0.02	50.00
NO_3-N	W. spinach	3.13 ± 0.35	0.58 ± 0.06	81.47
	Control	3.13 ± 0.23	1.60 ± 0.20	48.88
PO_4^{3-}	W. spinach	5.23 ± 0.45	1.04 ± 0.15	80.11
	Control	5.23 ± 0.25	3.03 ± 0.15	42.26

A wide range of TSS concentration in the effluent of fish aquaculture facilities was reported by several authors. Values from 8 to 32 mg/L of this study for planted and control trough, respectively were in accordance with the published range of 1 to 50 mg/L (Franco-Nava et al., 2004). Percent TSS reduction for planted and control troughs were 88.95% and 56.09%, respectively. Snow and Ghaly (2008) examined the use of hydroponically grown barley to reduce the TSS concentration in wastewater from a system stocked with Arctic charr (*Salvelinus alpinus*). The TSS reduction of 27.4% and 52.7%, 59.4% and 60.5% were achieved in the control trough and in the compartments containing barley (200, 250 and 300 g/tray), respectively. A possible mechanism for the removal of suspended solid was sedimentation, a process by which suspended particles settle from a wastewater under the influence of gravity. Results of this study are better than reported by Snow and Ghaly (2008), even though there is no sedimentation tank used. Utilization of vegetable in gravel bed and sand filter may improve treatment performance by enhanced sedimentation.

The average removal efficiency of TAN in the planted trough was 92.77%. Generally, the percentage of TAN removals of African catfish are hydroponically grown water spinach were within the range reported by other studies for other species (Vaillant et al., 2004; Lin et al., 2005; Snow and Ghaly, 2008; Hu et al., 2015). Several mechanisms exist for the removal of TAN from the aquaculture wastewater. Forms of inorganic nitrogen that were associated with the particulate matter may be removed from waste streams by sedimentation and filtration/interception by the root mats of plants. Ionized ammonium (NH_4^+) was one of the major sources of inorganic nitrogen is taken up by the roots of higher plants (Vaillant et al., 2003). It may be assimilated by microorganisms and converted back into organic matter or may be removed from waste streams through the process of nitrification. Based on this study, the concentration of TAN in the final effluent was comparatively low (0.06–0.43 mg/L), which is lower than the recommended TAN concentration of 3.0–6.7 mg/L for water used for the culture of African catfish (Eding and Kamstra, 2001).

The concentration of NO_2^--N in the hydroponic trough influent was in the range of 0.13–0.20 mg/L. At the end of the growth period, this system effectively removes 93.75% NO_2^--N in recirculation water. Hu et al. (2015) examined the use of hydroponically grown tomato for the treatment of wastewater from an RAS stocked with tilapia and reported NO_2^-–N concentration was maintained below 4 mg/L and no significant fluctuation was observed after day 45. In this study, the continuous aeration by air stones in the system compartments will facilitate the nitrification process. Although NO_2^--N was considerably less toxic than NH_3-N, it may be more important than ammonia toxicity in intensive recirculation system because it tends to accumulate in the recirculated water as a result of incomplete bacterial oxidation (Jo et al., 2002). The values of NO_2^--N concentration in the final effluent was in the range of 0.009-0.010 mg/L. This level was well below the toxic level for culture African catfish of 0.4–1.5 mg/L for NO_2^--N as recommended by Eding and Kamstra (2001).

The aquaculture wastewater in this study had NO_3^--N concentration in the range of 2.8 to 3.5 mg/L. NO_3^--N accumulates in aquaculture systems as a result of nitrification (Randall and Tsui, 2002; Hu et al., 2012). At the end of the growth period, NO_3^--N reductions in the range of 81 - 83%. Nitrate levels were significantly reduced in planted trough compared to the control trough. This was further evidenced that nitrate was assimilated by plants. Hu et al (2015) investigated the effect of plant species on nitrogen recovery in aquaponic and reported nitrogen uptake by plants played an important role in avoiding the accumulation of NO_3^--N in aquaponics. Lennard and Leonard (2006) evaluated the feasibility of utilizing a nutrient-film technique (NFT) to reduce the mineral content of wastewater from aquaponics system stocked with Murray cod (*Maccullochella peelii peelii*) and Green Oak lettuce (*Lactuca sativa*). During a three-week period, nitrate nitrogen concentrations in the effluent were reduced from 55.67 to 15.70 mg/L and resulting in an overall reduction efficiency of 71.8%. This study revealed a comparatively higher performance in apparent nitrate removal compared to another study (Lennard and Leonard, 2006; Snow and Ghaly 2008; Hu et al., 2015) due to the difference of HLRs and culture time operated, in which higher HLRs and lower duration were employed by other studies. Increasing HLR would reduce the contact time for nitrate uptake by plants root and denitrifying bacteria, thus decreasing the performance of hydroponics trough for denitrification process.

The mechanisms responsible for the removal of NO_3^--N were probably assimilated by microorganisms in the water column or by biofilms associated with the root mats of plants. Nitrification or oxidation of ammonia (ammonified and excreted ammonia) to nitrate as an oxygen demanding process occurred in two steps involving microbial species, e.g. Nitrosomonas and Nitrobacter (Matsumoto et al., 2010). In this study the concentrations of NO_3^--N in the final effluent of planted troughs were in the range of 0.52 – 0.65 mg/L, which was lower than 23 mg/L as recommended by Zweig et al. (1999) for the culture of fish and shellfish.

The concentration of orthophosphate (PO_4^{3-}) in each compartment increased with time during the germination period due to the release of dissolved and suspended matters from the developing seeds (Nelson, 2004). Average percent removal for orthophosphate was 80.11%. Food residues and fecal matter were the major sources of phosphorus in aquaculture effluent. PO_4^{3-} occurs in aquaculture wastewater primarily as soluble and insoluble phosphates in both organic and inorganic forms (Randall and Tsui, 2002).

Snow and Ghaly (2008) evaluated the use of hydroponically grown barley for removal of PO_4^{3-} from a system stocked with Arctic charr (*Salvelinus alpinus*) for 21 days and reported PO_4^{3-} reductions ranging from 87.1 to 95.1% in compartments containing barley (200, 250 and 300 g/tray, respectively). Lennard and Leonard (2006) examined the hydroponics gravel sub-system stocked with Murray cod (*Maccullochella peelii peelii*) and Green Oak lettuce (*Lactuca sativa*). After 21 days of the experiment, an overall reduction efficiency of PO_4^{3-} was 52.5%. This study revealed comparatively difference performance in PO_4^{3-} removal compare to other studies (Lennard and Leonard, 2006; Snow and Ghaly, 2008; Jin et al., 2010) due to the difference in seed quantity, HLRs, culture time operated and plant species.

Several mechanisms are responsible for the removal of PO_4^{3-} from wastewater. Forms of phosphorus that were associated with the particulate matter may be removed from wastewater by sedimentation or filtration by the root mats of plants. Soluble inorganic phosphate may be removed from waste streams by plant uptake, microbial assimilation, and precipitation with cations such as aluminum, calcium, magnesium, iron and manganese and adsorption onto organic matter (Vaillant et al., 2003). The average PO_4^{3-} concentrations in the final effluents from this study were in the range of 0.9 – 1.2 mg/L, which was lower than 2.6 mg/L as recommended by Kioussis et al. (2000).

Conclusion

The importance of integrating aquaculture and agriculture is clearly expressed throughout this study. Water spinach has the ability to reduce the pollution potential of aquaculture wastewater and can be used in small-scale farms to treat aquaculture discharge with the purpose of improving the quality of irrigation water. During the experiment, the plant grew rapidly and showed no signs of mineral deficiency or disease. The average plant heights at harvest were 45 – 50 cm. The average growth rate and crop yields were in the range of 1.7 to 3.2 cm/day and 3.50 to 3.80 kg/m^2, respectively.

High growth rates in fish adult seem to be associated with high productions and food conversion efficiencies. The overall relationship evaluation undertaken in this study indicated that the relationship can adequately predict fish growth for the purposes of current use and awareness of farmers regarding of feed management, which, in turn, might increase farmer operational management skills. This is particularly relevant because feeds and feed-related nutrient emissions are associated with the most important environmental burdens resulting from intensive aquaculture.

The hydroponically grown water spinach was able to significantly reduce the pollution load of the aquaculture wastewater. Removal efficiencies for BOD_5, TSS, TAN, NO_2^--N, NO_3^--N, and PO_4^{3-} were 82%, 89%, 93%, 94%, 81%, and 80%, respectively.

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