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Assessment of water quality in media-based aquaponic culture in Bangladesh

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ABSTRACT

Water is the major and foremost concern in aquaponics and its quality indicates whether the system is functioning properly or not. Hence, the present study was conducted to evaluate the quality of water used in the combined culture of Nile Tilapia (n=60, juveniles) and water spinach (n=4) in aquaponic system using two different media for 90 days. The experiment was carried out with the two treatments (T_1= brick lets, and T_2= mixture of brick lets and used tea leaves) with three replications each. Water quality parameters such as pH, temperature and dissolved oxygen (DO) were measured bi-weekly using water testing kits, and found in a suitable range for tilapia culture, though temperature was little bit higher than the favorable range. Electric conductivity (EC), carbonate (CO_3), hydrogen carbonate (HCO_3), total nitrogen (Total-N), phosphorous (P), potassium (K), sulphur (S), sodium (Na) were tested in the Humboldt Soil Testing Laboratory, Department of Soil Science, Bangladesh Agricultural University (BAU), Mymensingh, and found higher in influent water than the effluent water due to bacterial activity in the media and roots of plants which indicated the proper utilization of fish waste by the plants. Therefore, it could be concluded that whole system was working properly and there was a perfect symbiosis between fish, microorganisms and plants.

INTRODUCTION

Aquaponic, the perfect engineering of ecology, is the combination of aquaculture (fish or crustaceans) and hydroponic cultivation of plants (hydroponic vegetables, flower, and/or herb) in a re-circulating system, utilizing the nutrients present in the aquaculture effluents to produce plants with commercial value (Gallardo-Colli et al., 2014; Yildiz et al., 2017). Fish welfare in aquaponic systems can be an important criterion for the consumers worldwide. In addition, it is well established that optimal growing conditions are necessary to fulfill the essential physiological requirements to promote fish health and welfare. Hence, water quality parameters are of major concern in aquaponic system.

In aquaponic culture, the waste products are utilized as nutrient source by the plants and thus, filter dissolved waste products from the system. As a result, the need of any biological or chemical filtration is reduced for water changes and water quality management (Endut et al., 2009). Consecutively, the bio filter, hydroponic beds, stripped off ammonia, nitrates, nitrites, and phosphorus, thereby, almost freshly cleansed water are re-circulated back into the fish tank. The nitrifying bacteria habitats in the gravels and in close association with the plant roots play a critical role in nutrient cycling (Goddek et al., 2015) (Figure 1).

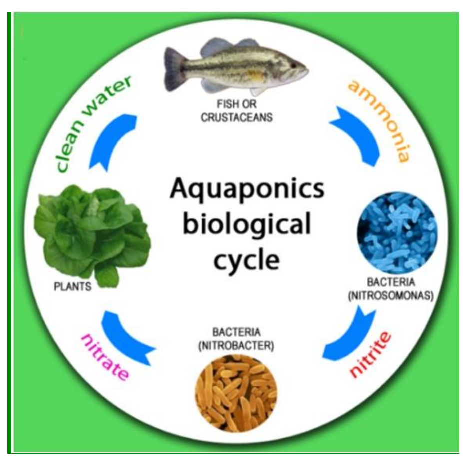

Figure1
Principles of the aquaponic system.
(www.aquaponicsiberia.com/aquaponia/?lang=en)

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The dissolved nutrients from fish effluent has the role to increase plant biomass, and ultimately, reduce the environmental effects associated with food production on land (Ghaly et al., 2005).

Aquaponic culture of fish requires good water quality conditions, i.e. dissolved oxygen, carbon dioxide, ammonia, nitrate, nitrite, pH must be within acceptable species-specific limits (Mancuso, 2013). Water quality parameters are usually observed in many aquaculture operation to identify hazards for the welfare risk assessment. Regular observation and recording of critical water quality parameters is essential, as rapid changes in water quality might happen due to sudden fluctuation in fish stocking density, growth rate, feeding rate or water volume changes, which may affect fish physiology, growth rate, and feed efficiency, leading to pathological changes and even mortality under extreme conditions (MacIntrye et al., 2008).

In aquaponics, among all the environmental factors, water quality is the major and foremost consideration as it markedly affect fish health (Ekubo and Abowei, 2011). Various negative stimuli may arise due to inappropriate levels of water quality parameters which very commonly affect physiology, growth rate and feed efficiency (biomass increase/feed fed). The stabilization of the chemical composition of water normally requires some adjustments depending on the temperature and a range of other factors such as stocking density, from the aquaponics perspective, as this stability may set the biological limits for sustainable production. The complex interactions between water quality parameters may affect the welfare conditions of both plants and fishes due to unstable water conditions resulting from the production format for co-cultured species (aquatic organisms and plants) in aquaponic system (Endut et al., 2009). Even, this may impair the biological capacity of the fish in aquaponic system. Hence, experiment regarding water quality of aquaponic system in Bangladesh is of great importance for sustainable agricultural development.

Therefore, the present research work was conducted to assess the re-circulating water quality of aquaponic system using two different media in Bangladesh.

MATERIALS AND METHOD

Study area and duration the experiment

The experiment was carried out in the aquaponic Laboratory which situated in the southern side of the Faculty of Fisheries, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh. The experiment was conducted for 96 days from 08th June to 12th September 2014 to assess water spinach production in aquaponic system using two different media.

Experimental layout

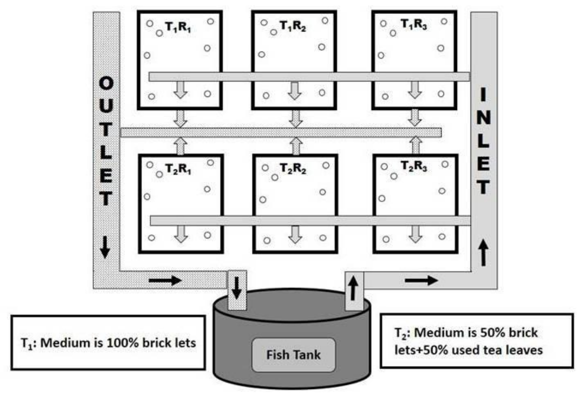


Figure 2
Experimental design of the study.

Various types of aquaponic system exist among which media based aquaponic system was chosen to conduct the present experiment. The design of the study comprises a fish holding tank and six food grade plastic containers to hold the media. Two types of media were used in this experiment that was 100% brick lets (8-10 cm size) and brick lets mixed with used tea leaves (1:1 by volume). All the beds were in equal size (43.7 x 26.8 x 24.5 cm^3) for the treatments. The treatments were indicated as T_1R_1, T_1R_2, T_1R_3, T_2R_1, T_2R_2 and T_2R_3 (Figure 5). The size of the circular fish tank was 68 cm×51 cm (750 Volume liters). Two 10 watt air pumps with two ports fitted with 4 air stones were used in fish tank to supply oxygen. The waste water from the fish tank was irrigated to the vegetable bed by a 12 watt submersible water pump.

An inlet and outlet pipes were set to the tank. The water was re-circulating the system. Two small

PVC pipes were connected to the plastic pipe where containers containing plants were placed. Small pipes were connected to the end of the plastic pipe through which waste water circulated from the fish tank with the help of water pump. A PVC pipe was connected to each container with another plastic pipe to the outlet pipe to drain the water in the fish tank.

Fish tank preparation

The fish tank was bought from local market and prepared before starting the experiment. Preparation of tank included cutting of upper end, washing, liming, plumbing pipes; setting brick lets and fills up the tank with underground water. At first, the upper part of the tank was cut out to make an opening for feeding the fish and cleaning the tank. It is essential to wash the fish tank with disinfectants mixed with water before starting the fish culture to remove the chemicals if any. The pipes were set to make an inlet and outlet. Two air pumps with four air stones were set to supply dissolve oxygen. The tank was then filled with brick lets of 2-5 cm diameter up to six inches at the bottom of the tank. Before placing the brick lets they were washed with clean water and finally the tank was filled with water from overhead tank. A separate filter was used to filter the fish tank water and placed over the fish tank (Figure 3).

Figure 3
A 750 liter water tank used for Fish rearing.

Stocking of fish

Mono sex tilapia fingerlings were used as the experimental animals which was brought from a local hatchery and used in another aquaponic experiment. The collected fish was acclimatized and released to the experimental fish tank. Good and healthy fingerlings were selected for the experiment. Before stocking the fingerlings were disinfected with potassium permanganate solution (2 mg/L for 4 to 5 hours). Prior to release fingerlings the fish was acclimatized for 15 minutes for each degree change in temperature and for every unit change in p^H. After acclimation, 60 fingerlings of tilapia were released into the tank on 4th June, 2014 (Figure 3).

Feeding the fish

The commercial floating feed (1-- 3 mm size) containing 30% protein was used to feed the fish. The feed was bought from the local fish dealer of Mymensingh town. The feed was supplied twice daily, first in the morning at 9:00 AM and in the afternoon at 5:00 PM at the rate of 3% body weight initially. Over feeding was avoided as uneaten feed make the fish tank water unsafe for fish and will lead to water quality degradation. Later on the feed was reduced to 3%of the fish body weight.

Physico-chemical parameters of the fish tank water

To know the quality of the water the physico-chemical parameters of tank water was measured. Dissolved oxygen (DO), temperature and pH were measured every 15 days interval. Chemical test kits were used to test the physic-chemical parameters. Total nitrogen (Total-N), electric conductivity (Ec), carbonate (CO_3) hydrogen carbonates (HCO_3), potassium (K), sulphur (S), sodium (Na) and calcium (Ca) were measured three times at one month interval during the experiment. The tests were done in the Humboldt Soil Testing Laboratory at Soil Science Department, Bangladesh Agricultural University (BAU), Mymensingh.

Collection of water sample

Water sample was collected from the fish tank and from the outlet of water spinach bed. Small bottles were used to collect the sample and marked as Bottle-1 for tank water and Bottle-2 and Bottle-3 for outlet water. Tank water was before treatment and outlet water was after treatment. Sample collection was done at the morning. The water sample was collected from the column of the water tank by keeping the bottle in invert position and sank into the tank water by hand and turns up right when it was in the mid-level of the tank. The second sample was collected from the outlet pipe of water spinach bed using another bottle. After collection of the samples they were brought to the Humboldt Soil Testing Laboratory at BAU.

Dissolved oxygen (DO) measurement

Dissolved oxygen was measured at 9 am by DO meter. At first DO meter was turned on and the probe of the DO meter was sank into the tank water by using hand and kept it for some time. In that time increasing or decreasing of reading of dissolve oxygen was carefully observed. Then DO meter was raised from the tank and reading was recorded. The unit of dissolve oxygen measurement was parts per million (ppm).

Temperature measurement

Temperature was measured regularly at 9:00 AM. A thermometer was used to measure the water temperature of the tank. At first the thermometer was turned on. Then the probe of it was sank into the tank water by using hand and kept it for some time. Then the thermometer reading was recorded. The unit of temperature measurement was degree Celsius ($^{\circ}$C). After using the thermometer it was turned off and extra water was removed by the tissue and kept it for further use.

pH measurement

pH was measured by using pH meter. At first pH meter was turned on. Then the probe of it was sank into the tank water by the hand and kept it for some time. In that time increasing or decreasing of reading of pH was carefully observed. After sometime a beep signal was given by the pH meter then the movement of the pH meter reading was stopped. Then pH meter was raised from the tank and reading was recorded carefully. After using the pH meter it was turned off and the extra water on the pH meter was removed by the tissue and kept it in safe place.

Data processing and analysis

The data entry was done in "Microsoft Excel 2007". Collected data were summarized carefully before final tabulation. Preliminary data were transferred into master sheet and prepared tables and Figurers to show the findings of the experiment. After completion of the data entry in "Microsoft Excel 2007" it was used to perform descriptive statistical analysis of data. M-Stat was also used to calculate the significance level of the three treatments data.

RESULTS AND DISCUSSION

Water quality parameter

Water quality parameters play an important role in the health and growth development of aquatic organisms. So to maintain good quality water for smooth culture practice in aquaponic system the following water quality parameters such as pH, temperature and dissolve oxygen of fish tank water were measured during the study period (Table 1).

Table 1
Physical parameters of fish tank water observed in different dates.

Date	PH	Dissolved oxygen (ppm)	Temperature (^{0}C)
08-06-14	7.7	4.8	29.3
30-06-14	7.8	3.8	29.5
08-07-14	7.7	4.7	27.6
30-07-14	7.6	3.6	28.6
08-08-14	8.4	4.1	27.9
30-08-14	7.7	3.9	28.1
Mean	7.82 ± 0.608	4.15 ± 0.603	28.50 ± 2.55
Level of Significance	NS	NS	NS

NS: Non Significant

pH

The variation of pH values in different dates is presented In Table 2. During the study period the mean pH value in fish tank water was 7.82 ± 0.61. The minimum pH value was 7.6 was recorded on 30th July, whereas, the maximum value was 8.4 on 8th August (Figure 4). In the system there were no significant differences of pH value in different dates.

The negative logarithm of hydrogen ions concentration is considered for pH measurement mathematically. The concentration of carbon dioxide greatly influences the pH of natural waters (Boyd 1979). Ekubo and Abowei (2011) mentioned that the average pH of a closed water body is 7.4; the range of 7.0 to 8.5 is optimum and favorable to fish growth, whereas pH 4.0 to 6.5 and 9.0 to 11.0 is stressful for fishes and fish can die at once at pH less than 4.0 or greater than 11.0. Plants in aquaponic system grow best at pH 6.0-6.5 and the nitrifying bacteria perform best at pH 6.8-9.0 (Nelson, 2008). In the present study the average pH value in fish tank water was 7.82 and range from 7.6 to 8.4. The pH range of the present study was suitable for tilapia culture.

Temperature

During the study period, the mean water temperature of the fish tank water was 28.50 ± 2.55 °C. The minimum and maximum water temperature were 27.6 °C on 8th July and 29.5 °C on 30th June respectively (Table 1 and Figure 4). There were no significant differences of temperature in different dates.

Temperature has an effect on DO as well as on ammonia toxicity; in high temperature level, DO level decreased and unionized ammonia level increased. The research findings reported that different strains of tilapia have different temperature tolerance ranges required for optimal growth. Bhatnagar *et al.* (2004) suggested the level of temperature 28-32 ^{0}C is good for major carps growth. In aquaponic system, tilapia is usually maintained between 25.2 and 28.3 °C (Nelson 2008). On the other hand, in the present study the temperature range varied from 27.6 to 29.5 °C with average temperature 28.5 °C into the tank water. The temperature range was within the suitable range for tilapia culture.

Dissolve oxygen

Dissolve oxygen (DO) content variation in different dates in the fish tank water is presented in table 2 and Figure 4. During the culture period the mean dissolve oxygen content in the fish tank was 4.15 ± 0.60 ppm. The lowest and the highest DO values were 3.6 on 30th July and 4.8 ppm on 8th April respectively.

Dissolve oxygen content is very important factor in fish culture as fish can die at low DO content. Ekubo and Abowei (2011) mentioned that fish can die if exposed to less than 0.3 mg L^{-1} of DO for a long period of time. However, tilapia is a hardy fish that can survive in low DO content than other fishes. In the present study, the range of DO content in water was 3.6 to 4.8 ppm and the average was 4.15 ppm. It is recommended that the DO levels be maintained at 5.00 ppm or higher in aquaponic system, depending upon the fish species (Sallenave, 2016). So in the present experiment, DO level was in acceptable range for growth and survival of tilapia in the fish tank.

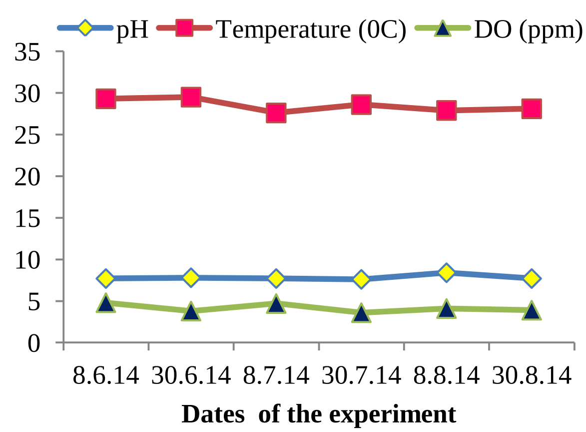


Figure 4
Variations of water quality parameters measured in different dates.

Lab test results of Fish tank water

Electric conductivity (EC), carbonate(CO_3) hydrogen carbonate (HCO_3), total nitrogen (N), phosphorous(P), potassium(K), sulphur(S), sodium(Na) were measured two times at one month interval in the lab named as Humboldt Laboratory at Soil Science Department, Bangladesh Agricultural University (BAU). The results of the fish tank water test are shown in the following table (Table 2).

Table 2
Results showing the tank and outlet (1, 2) water analysis in two months.

Elements	July			September		
	Inlet	Outlet-1	Outlet-2	Inlet	Outlet-1	Outlet-2
EC (μs/cm)	394 ± 11	336 ± 9	334 ± 10.2	598 ± 17.5	737 ± 9.5	469 ± 13
HCO_3 (ppm)	189.1 ± 9.31	237.0 ± 7.21	79 ± 8.5	219.6 ± 8.1	213.5 ± 7.51	323.3 ± 11
CO_3 (ppm)	72 ± 6.7	18 ± 2.78	114 ± 9.6	12 ± 1.68	72 ± 4.78	0
Total-N (ppm)	4.2 ± 0.92	7 ± 0.81	4.2 ± 0.71	11.2 ± 1.02	5.6 ± 0.7	0
P (ppm)	0.823 ± 0.11	0.502 ± 0.11	0.193 ± 0.09	1.69 ± 0.07	0.15 ± 0.01	1.092 ± 0.01
K (ppm)	15.13 ± 1.15	16.54 ± 1.17	14.93 ± 1.17	14.5 ± 1.17	2.62 ± 0.02	6.445 ± 1.1
S (ppm)	3.509 ± 0.27	3.642 ± 0.21	3.51 ± 0.10	8.96 ± 0.97	1.48 ± 0.01	3.93 ± 0.21
Na (ppm)	43.99 ± 4.87	46.84 ± 4.11	43.17 ± 3.52	No Test	No Test	No Test

Note: (1) Values are given with ± standard deviation
(2) Outlet-1: Only brick lets Media, Outlet-2: Mixture of brick lets and used tea leaves based media

Electric conductivity of fish tank water

The highest value of electric conductivity was found in outlet-1 water was 737 ± 9.5 μs/cm during September. At the same time the EC value in inlet and outlet-2 were respectively 598 ± 17.5 μs/cm and 334 ± 10.2 μs/cm. On the other hand, in outlet-2 the lowest value of EC 334 ± 10.2 μs/cm was found on July. At the same time the EC values in inlet and outlet-1 were 394 ± 11 μs/cm 336 ± 9 μs/cm (Table 2 and Figure 5a).

The capability of certain solution to pass the electric current is called electric conductivity, which indicates the concentration of dissolved electrolyte ions in the water. Moreover, enough nutrients for plant growth is marked by significant increases in conductivity. In most cases, higher conductivity means the presence of various ions including nitrate, phosphate, and sodium in the water, which are beneficial for plant growth. The basic unit of measurement for conductivity is micromhos per centimeter (μmhos/cm) or microsiemens per centimeter (μS/cm). It is the measure of inversion of the amount of resistance of an electric charge that is traveling through the water. Rodriguez-Delfin et al. (2000) reported that EC for lettuce should not exceed 2500 μS/cm, whereas, in the present study EC in aquaponic system was 598 μS/cm in inlet and 469 μS/cm in outlet water which indicated the proper utilization of nutrients by the plants in the system (Rakocy et al., 2004).

CO_3 of fish tank water

The height CO_3 value was found in outlet-2 was 114 ± 9.6 ppm in July and lowest value was in inlet 12 ± 1.68 ppm in September. On the other hand no CO_3 was found in outlet -2 in that time (Table 2 and Figure 5b).

The amount of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) dissolved in water is very important indicator for fish culture. It is also measured in milligrams of $CaCO_3$ per liter. In general, water is considered to have high level of bicarbonate (121–180 mg/L) (Soimerville et al., 2014). The carbonate hardness present in water has an impact on the pH level. Bi carbonate simply acts as a buffer (or a resistance) to lowering of pH. Carbonate and bicarbonate present in the water can bind the H^+ ions released by acids, thus removing the free H^+ ions from the water. Therefore, the pH will stay constant even as new H^+ ions from the acids are added to the water. This buffering is important, because rapid changes in pH are stressful to the aquaponic system.

Hydrogen carbonates analysis

The highest value of hydrogen carbonate was 323.3 ± 11 ppm found in outlet-2 water in September, whereas, the values were 737±9.5ppm and 598 ±17.5ppm in outlet-1 and inlet water at the same time. By contrast, the lowest value of hydrogen carbonate was 79 ± 8.5 ppm found in outlet-2 water in July where in outlet-1 and the inlet values were 237.0 ± 7.21 and 189.1 ± 9.31 ppm (Table 2 and Figure 5c).

The nitrification process generates nitric acid (HNO_3), which is dissociated in water in two components, hydrogen ions (H^+) and nitrate (NO_3^-), with the latter used as source of nutrients for plants. The higher the concentration of HCO_3 in the water, the longer it will act as a buffer for pH to keep the system stable against the acidification caused by the nitrification process (Somerville *et al.*, 2014). In the current study it is observed that the HCO_3 level was low (189.1ppm) at the initial stage of the experiment in the fish tank water and finally at the last month the HCO_3 concentration was higher (323 ppm) due to above reasons. So during the experiment the HCO_3 level of the fish tank water was within the suitable limit.

Total-N analysis of fish tank water

The highest value of total-N was 11.2 $\pm$ 1.02 ppm which was found in the inlet water in September. In that time its value was 5.6 $\pm$ 0.7 ppm in the outlet-1 and no total-N were found in outlet-2 water. On the other hand, the lowest value of total-N was 4.2 $\pm$ 0.72 ppm found in outlet-2 water in July whereas; in the inlet and outlet-1 water the values were 4.2 $\pm$ 0.92 ppm and 7 ± 0.81 ppm (Table 2 and Figure 5d).

Nitrogen is the fourth crucial water quality parameters which enter in an aquaponic system from the fish feed and other wastes. Although toxic to fish, nitrogen compounds are nutritious for plants and are the basic component of plant fertilizers. In a fully functioning aquaponic system ammonia and nitrite level need to be closed to zero or at least 0.25–1.0 mg/L (Somerville et al., 2014). The bacteria present in the media convert almost all the ammonia to nitrite and then nitrite into nitrate which is used valuable nutrient for plant. In the present study, it was observed that the total-N level was very high initially (4.4 ppm) which was gradually been decreased to 0 ppm. This was due to bacterial activity in the grow bed which was favorable for the fish growth in the tank.

Phosphorus analysis

The highest value of phosphorus was 1.686 $\pm$ 0.07 ppm that was found in the inlet water in September. During that time 0.145 $\pm$ 0.011 ppm in outlet-1 and 1.092 ± 0.0089 ppm in outlet-2 was found. By contrast, the lowest value was 0.145 $\pm$ 0.011 ppm found in outlet-1 in September. In the same time inlet water was 1.686 $\pm$ 0.07 ppm and outlet-2 water was 1.092 ± 0.0089 ppm respectively (Table 2 and Figure 5e)

Potassium analysis

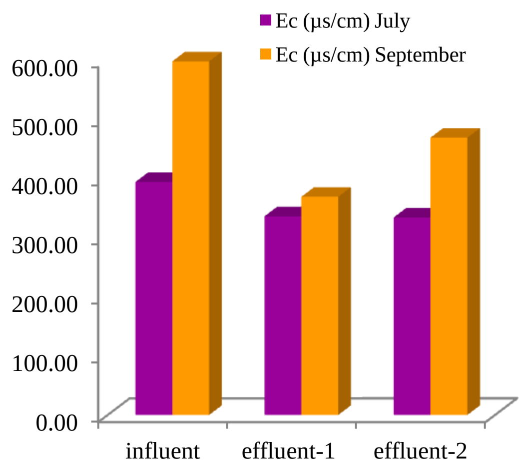
The highest value of potassium was 16.54 ± 1.17 ppm in the outlet-1 water in July at the same time the outlet-2 was 14.93 ± 1.17 ppm and inlet was 15.13 ± 1.15 ppm. On the other hand, the lowest value 2.618 $\pm$ 0.017 ppm was found outlet-1 in September, during this time inlet was 14.5 $\pm$ 1.17 ppm and outlet-2 was 6.445 ± 1.1 ppm (Table 2 and Figure 5f).

Sulphur analysis

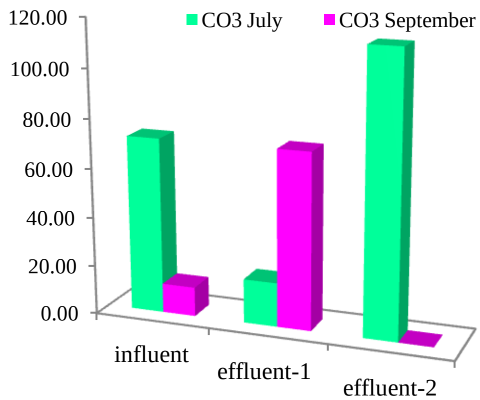
From the analysis it was observed that both highest and lowest value of Sulphur found in inlet which was 8.96 $\pm$ 0.97 ppm and in outlet- 1 was 1.48 $\pm$ 0.0081 ppm in September. When in outlet-2 the value was 3.93 ± 0.21 ppm during that time (Table 2 and Figure 5g).

Sodium analysis

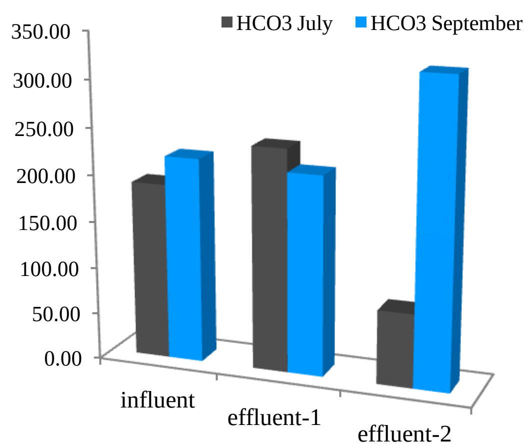
The highest value of sodium was 46.84 ± 4.11 ppm found in outlet-1 water and lowest value was 43.17 ± 3.52 ppm in inlet water both values were found in July. No test was done for Na in September due to insufficient chemicals in the laboratory (Table 2 and Figure 5h).



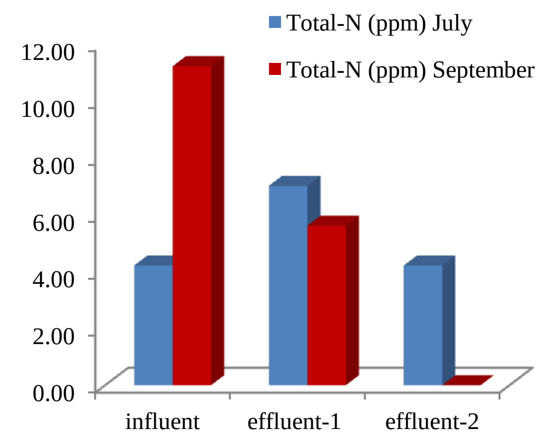
a. EC test result



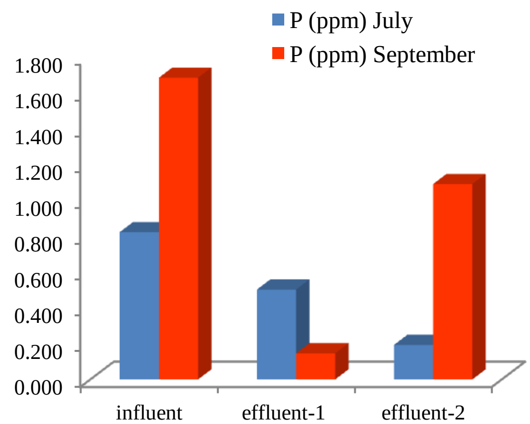
b. CO_3 test result



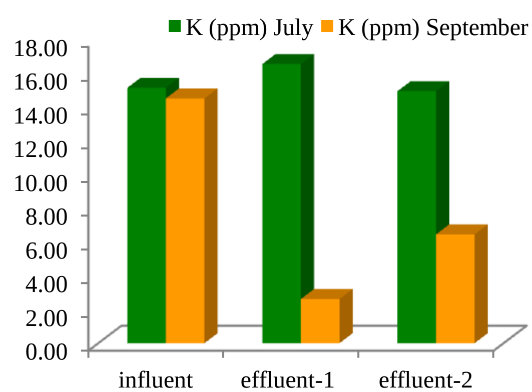
c. HCO_3 test result



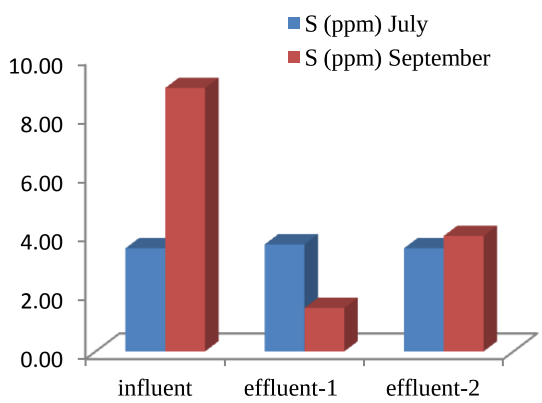
d. Total-N test result



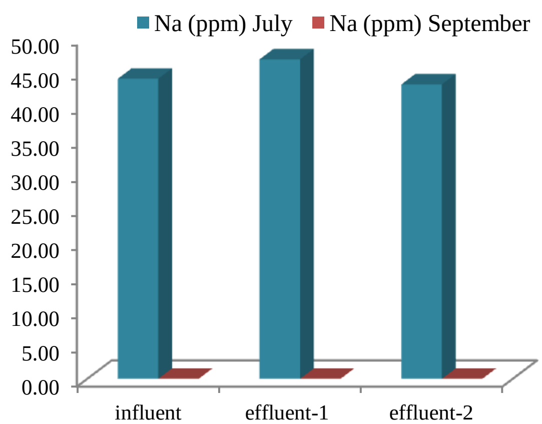
e. Phosphorus test result



f. Potassium test result



g. Sulpher test result



h. Sodium test result

Figure 5
Water quality parameter results for inlet and outlet water (a, b, c, d, e, f, g and h).

Fish waste produced nutrients such as P, K, and Na in fish tank water which were then utilized by plants as a source of nutrient. In the present study, P ranged from 0.15 to 1.69 ppm, where Rackoy et al. (2006) reported that tolerable limit of P in aquaponic system is in between 0.20-1.15 ppm. So, the P concentration in the present study was within the optimum range for plant growth.

The concentration of Na+ in the aquaponic system was 43.17 to 46.84 ppm. Rakocy et al. (2006) mentioned in his research that the Na+ concentration in aquaponic system should not exceed 50 ppm. So the Na+ level in this study was in a suitable level.

CONCLUSION

The higher amount of EC, P, K, S, Na, CO3 and Total-N in influent water than effluent indicates bacterial activity in the media and roots of plants, ultimately proper utilization of fish wastes by the water spinach. The whole aquaponic system worked at desired level, and this could be a part of sustainable agricultural production in Bangladesh.

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