Tilapia Powered Aquaponics to Optimize Land and Water Use for Safe Food Production from the Rooftop

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Abstract—*Tilapia powered vertical aquaponics system (TPVAS) is an effective way to increase crop production in a food desert city per unit rooftop area by extending crop cultivation into the vertical dimension to feed the ever-increasing population of the world and keep the city-pollution free and cooler. Experiments conducted over the years to assess the viability of tilapia powered lettuce, strawberry, water spinach and mint production in the media-based vertical aquaponics system at the rooftop and lab of Bangladesh Agricultural University, Mymensingh, Bangladesh. The wastewater of the tilapia tank irrigated to the 4 feet height and 3-4-inch diameter vertical plastic pipes holding 15 to 18 saplings in each pipe which passing through the coco dust, coco coir, water hyacinth root, and brick chips media then return into the fish tank again. Fish growth performances, nutrients availability, and their use assessed. The mean length and weight gain of tilapia were 2.95 (±0.83) to 11.77 (±2.49) cm and 32.71 (± 9.43) to 170.38 (±78.7) g. The feed conversion ratio (FCR) were 2.5, 2.35, 2.33 and 1.5 and survival rates were 96, 78, 85 and 98.33% for lettuce, strawberry, water spinach and mint based tilapia aquaponics systems. The fish and vegetable production was 30.64 to 135.20 and 12.47 to 123.25 MT/ha/90 to 120 days respectively. Among the four media, coco coir produced the highest crop than the others.Therefore, it is concluded that the TPVAS is suitable and capable of producing fish and vegetables at the rooftop keeping the rooftop cooler and greener than nearby traditional roof gardening buildings.*

Keywords—Fish well-being, Rooftop, Safe food, Tilapia, Vertical aquaponics.

I. INTRODUCTION

The world population will reach 9.6 billion by 2050, 34 percent higher than the present population. Most of the population increase will occur in developing countries like Bangladesh (Kodmany, 2018) where agricultural land is shifting to other uses day by day. Global food production will face great challenges in the future as the rice-growing field has decreased by 18% from 1971 to 2015 (BBS, 2016; Christine and Gruda, 2015). Moreover, the natural calamities like cyclones, tornadoes, droughts, floods and river erosion destroys a significant amount of crops each year that threatened food security in the country. In addition, huge demand for seeds and fertilizers, higher transport costs, burning fossil fuel, and climate change impact are responsible for price hick of agricultural commodities in the country (Hugh, 2016) The scientists emphasized to grow food in the cities at the vicinity of the consumers to cut the transport costs and address climate change impact (Paxton, 1994; Wakeland, 2012).

Bangladesh is one of the world's leading fish producing countries with a total production of 4.134 million tons, where inland fisheries contributed 82.26% comprising 29.34% from capture fisheries and 52.92% from aquaculture (DoF, 2018). The fisheries sector plays an important role in lessening malnutrition, earning foreign exchange and improving the socioeconomic status of the rural small farmers of Bangladesh (Uddin and Farjana, 2012). Fish supply 60% animal protein to the countrymen and support the livelihoods of 11-12% fishermen (FAO, 2012). The country ranked 3rd place among the inland water fish producing countries and 5th in aquaculture (FAO, 2018). The farmers expanding aquaculture activities horizontally not addressing the environmental pollution and shortage of land (Marco and Kuenzer, 2016). In such a situation, environmental engineering and eco-friendly farming the "Tilapia Powered Vertical Aquaponics System" (TPVAS) can a substitute to resolve the problems (Katy, 2019). The TPVAS has been increasing popularity as a way to reduce the need for arable land and grow crops where they are to be consumed. When farming indoors, on rooftops and balcony in a closed or semi-closed environment, the plants are protected from the bad weather, insects, and pests (Liu *et al*., 2016). There are no losses of nutrients in closed systems and water use is less in comparison to traditional farming. However, artificial lighting is necessary while crops grow indoor. Additionally, TPVAS is capital intensive and requires knowing how to handle the new techniques and maintenance. The system combines ecology and environmental engineering to solve existing problems as well as address land crisis through utilizing unused space, beautifying the backyard and rooftop in a cost-effective and ecosystem approach (Kangas, 2004; Kheir, 2018).

Mint (*Mentha arvensis*) is a native aromatic herb which used to enhance the flavor of food in time immemorial as a component of the traditional drug for therapeutic purposes (Normala *et al*., 2010). From ancient time, the mint has played an important role in trade due to its diverse elements and applications (Sahil *et al*., 2011). It is famous as an indigenous herb in the Indo-Pak subcontinent for its well-being, taste, essential oil and defensive potential (Baliga and Rao, 2010). The mint contains moisture, protein, fat, minerals and vitamins, fibers and carbohydrate of 78.65, 3.75, 0.94, 0.9, 8.0, and 14.89% respectively. It also contents 70 Kcal of energy (The USDA National Nutrient Database, 2011). Moreover, the mint has been widely used as a traditional medicine for the treatment of anorexia, nausea, flatulence, bronchitis, colitis ulcer and liver anomalies due to its various health promoter activities (Hadjlaoui *et al.*, 2009). The leaves and essential oil are the dominant use of mint (Beemnet *et al*., 2010; Verma *et al*., 2010; Gul, 1994). By contrasts, strawberry (*Fragaria ananassa*) is bright red, juicy, sour and sweet in taste and rich in antioxidants and full of plant compounds that help to control heart health and blood sugar level. It is also an excellent source of vitamin C and manganese and has a small amount of folate (vitamin B9) and potassium. It is usually consumed raw and fresh, the berry can also be used in a variety of value-added products like jam, jelly, and dessert (Halvorsen *et al*., 2006; Giampieri *et al*., 2012). The lettuce (*Lactuca sativa*) is another favorite green leafy vegetable that is popular worldwide and consumed raw in salad and burger. It is crunchy and green which has many essential nutrients for health benefit (Liu, 2003; Pandey and Rizvi, 2009). In Addition, the leafy vegetable water spinach (*Ipomoea aquatica*) is also popular green vegetable which is rich sources of fiber, vitamins, and minerals (Anderson *et al*., 1994). Water spinach is a vegetable plant which has decent nutraceutical uses and is commonly eaten as a vegetable and mostly found in tropical and sub-tropical Asia, Indian sub-continent, Africa and Australia (Chitrajit and Pinak, 2015).Therefore, lettuce, strawberry, water spinach, and mint production experiments carried out in media-based TPVAS for integrated nutrient management, ease pressure on land resources and produce organic fruits and vegetables which have improved the physical, chemical and biological properties of soil less crop production as well as increased production from an unproductive unit of the rooftop area.

II. MATERIALS AND METHODS

2.1 Experimental site and set up

The experiments were carried out during a period of 90 to 125 days from 2014 to 2017 at the backyard "Aquaponics Oasis" laboratory and rooftop, Department of Aquaculture, Bangladesh Agricultural University (BAU), Mymensingh. Among different types of aquaponics systems, the media-based vertical aquaponics system selected to carry out the researches. The experimental design composed of twelve fish holding tanks, a 4-inch diameter 3 ft. long 48 PVC pipes, coconut coir, coco fiber, water hyacinth roots and brick chips as the growing media (Fig. 1). Four different types of media, coco dust and coco coir (T1 and T2), water hyacinth root (T3) and brick chips (T4) each having three replication used in those experiments to grow lettuce, strawberry, water spinach, and mint. Fifteen to eighteen holes at an equal distance created with the hole saw drill machine in each pipe. The pipes containing various media were hung from the above with a parallel bamboo pole in rows following completely randomized block design (CRBD), indicated as T_1R_1, T_1R_2, T_1R_3, T_2R_1, T_2R_2, T_2R_3, T_3R_1, T_3R_2, T_3R_3, T_4R_1, T_4R_2, and T_4R_3. Twelve 750 L capacity plastic water tanks used as the fish holding tanks in all the four treatments. An inlet and outlet pipes set and connected with the PVC pipes in all the treatments. Twelve 25-watt submersible pumps used to pump the fish tank water to the vertically set pipes having the growing media in each treatment. An air pump with air stones provided oxygen to the fish tanks for fish well-being.

The plastic water tank in each treatment cut off the upper part and washed properly for keeping the fish in. After setting the tank, a layer of 3-4-inch brick let's put at the bottom of the tank. The inlet and outlet pipes (Fig. 1) were plumber to pump the fish tank water to the vertical pipes. The hanging pipes in all the treatments filled with locally procured coconut coir, coco fiber, water hyacinth roots, and brick chips. Then all the (48) pipes hung from a horizontal bamboo pole at a sun-exposure spot at the rooftop of a building at BAU and "BAU Aquaponics Oasis" laboratory.

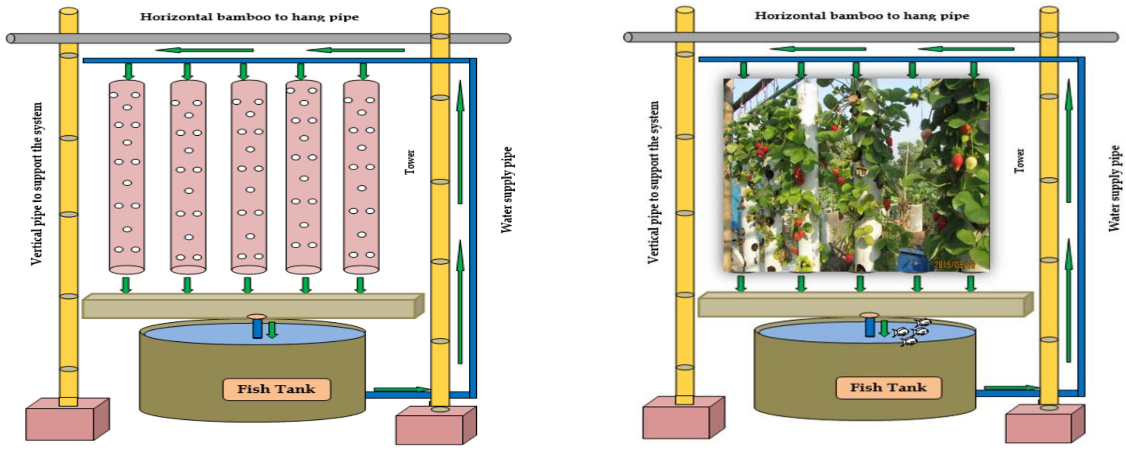

FIGURE 1: Experimental design with vertical pipe having 15 to 18 holes each in a 3 feet long pipe, water inlet and out let system in left and fruiting strawberry and fish in tank at right.

The healthy saplings of lettuce, strawberry, water spinach and mint of 6.5-10 cm size each planted in each hole in the pipes. In all the four treatments, the saplings uprooted from the soil or germinating pot and washed well with clean water before being transplanted into the pipes. Followed by planting the saplings, mono sex tilapia (181 fish/m^3 water) juveniles (*Oreochromis niloticus*) of 7.76 (± 2.14) to 15.26(±1.41) cm and 3.83(± 1.10) to 60.06(±17.69) g initial length and weight collected locally and released in each fish tank. Thirty percent protein-containing commercial floating pellet feed fed twice daily, at 9:00 AM and at 5:00 PM at the rate of 5% of fish body weight in 1st month, then the feeding rate was re-adjusted to 3 and 2% in 2nd and 3rd month. Fish tank water was irrigated with a submersible pump from the fish tank to the vertical pipes from the upper side which then passes through the pipes and finally falls in the fish tank again. The water pumps operated in the daytime only. The irrigation pipes, water pumps, air tubes, and air stones cleaned regularly to avoid clogging with algae and fish poo. No weeding was essential in the system; however, if there were any weed seen, they removed instantly.

2.2 Sampling the fish and vegetable and harvesting

The lettuce, strawberry, water spinach, and mint sampling carried out fortnightly but 1st harvest of lettuce, water spinach, and mint carried out after one month and strawberry harvested when ripe fruits were available. Following the harvest, their length, number of branches, leaf number and weight measured and recorded. Ten fishes sampled randomly caught from each replication of each treatment using a handheld scoop net. Length and weight of the fish measured with care and data recorded in the notebook and transferred into the computer later. The fish and all the vegetables were finally harvested after 90-125 days of the experiment. The length and weight gain calculated after harvest and % length gain and % weight gain, specific growth rate (SGR), feed conversion ratio (FCR), survival and fish production were also calculated.

2.3 Sampling water parameters

Physio-chemical parameters of fish tank water such as dissolved oxygen (DO), temperature and pH measured bi-weekly. The Sera water testing kits and Hanna® pH/Ec/TDS/DO meters used to sample the physio-chemical parameters of water. In addition, total nitrogen (Total-N), electric conductivity (EC), carbonate (CO_3^{2-}), hydrogen carbonate (HCO_3^-), potassium (K), sulfur (S), sodium (Na) and phosphorus (P) also measured twice during the experiment in all the treatments, 1st at the beginning and last at the end of the experiment at the Humboldt Soil Testing Laboratory, Soil Science Department, BAU.

2.4 Data processing and analysis

All the collected data were recorded and transferred into the computer and cross-checked for any mistake. The data were converted into a Microsoft Excel master sheet and prepared the tables and graphs. One-way ANOVA performed on the collected data using Xl-stat at a 95% significance level. Tukey's HSD (Honestly Significant Difference), Duncan's multiple range test and Fisher's LSD (Least Significant Difference) tests performed to test significant differences in triplicate and across the treatments means.

III. RESULTS AND DISCUSSION

3.1 Water quality parameters

Mint and water spinach experiments conducted in the summer when the environmental temperature was higher. On the other hand, lettuce and strawberry experiments conducted in winter from November to March from 2014 to 2017 when the temperature was lower than the rest of the year. The range of pH, temperature and dissolved oxygen of the water in the fish tank recorded throughout the culture period of 7.56(±0.19) to 7.83(±0.14), 21.56(±3.26) to 29.70 (±1.21°C and 3.86(±0.04) to 4.80 (±0.02) ppm. The minimum pH value was 7.30 on 25th January, 22nd February and 29th March, 2015. By contrast, the minimum and maximum water temperature were 14°C on 28th January 2015 in lettuce based tilapia production system and 29.70 (±1.21) °C on 4 September 2014 (Table 1). The present results suggested that a favorable range of pH for both fish and nitrifying bacteria in a vertical aquaponics system existed. The literature revealed that the pH range of 6.5 – 8.5 is appropriate for tilapia culture (Swingle, 1968; Huet, 1972; Makori *et al*., 2017), while, the nitrifying bacterial growth is withdrawn below the pH of 6.5 with an optimum pH of 7.8 favorable on species and temperature (Tyson *et al*., 2007; Alenka *et al*., 1998). The range of water temperature found in present experiments imitates the suitable range for tilapia culture and nitrifying bacteria in the aquaponics system (Wortman and Wheaton, 1991; Rahmatullah *et al*., 2010).

TABLE 1
Nutrient profile of influent and effluent water in water spinach tilapia basedvertical aquaponics system

Parameters	July-2014		August-2014	
	Influent	Effluent	Influent	Effluent
P (ppm)	0.832 (±0.11)^c	0.398 (±0.03)^d	1.686 (±0.11)^a	1.191 (±0.11)^b
K (ppm)	15.13 (±1.14)^a	15.53 (±1.18)^a	14.5 (±2.14)^a	4.632 (±0.74)^b
S (ppm)	3.509 (±0.16)^b	3.709 (±1.19)^b	8.96 (±1.16)^a	1.67 (±0.19)^c
Na (ppm)	43.99 (±7.17)^a	43.99 (±1.21)^a	39.531 (±2.11)^b	37.95 (±1.17)^b
HCO_3^-	189.1 (±17.13)^b	195.2 (±1.2)^b	219.6 (±28.13)^{ab}	256.2 (±51.13)^a
CO_3^{2-} (ppm)	72 (±6.12)^a	36 (±1.12)^b	12 (±2.12)^c	42 (±9.12)^b
Total N (ppm)	4.2 (±1.15)^b	3.2 (±0.15)^b	11.2 (±1.15)^a	5.6 (±1.15)^b
EC (µc/cm)	394 (±47.17)^b	338 (±31.21)^b	598 (±37.17)^a	391 (±58.17)^b

The values in the same column having similar letter (s) do not differ significantly, whereas, values bearing the dissimilar letter (s) differ significantly as per Duncan's multiple range tests. Values in the parenthesis indicate the standard error.

The nutrient values in the effluent water were lower than in the influent water in all the four vertical aquaponics system. However, the difference was sometimes significant and sometimes not in Fisher's LSD test (Table 1 and 2). The highest EC recorded in influent water in August 2014 (598 ±37.17) and May-2016 (662+2.83) in spinach-tilapia and mint-tilapia based vertical aquaponics system. Moreover, the nutrients had significantly or not significantly reduced in the effluent water at the end of the experiments because the plants extracted enough nutrients for their growth from the water at their growth stage. Werner *et al*. (2015) reported EC of 526.73 -753.53 (± 125.30) µc/cm in an aquaponics experiment in a greenhouse environment which is more or less similar to the present study.

The amount of carbonate and total-N were higher at the beginning but reduced significantly at the end of the experiment. However, carbonate had increased again in the effluent water at the end of the experiment, possibly the extraction reduced by mint and water spinach from the water. The total-N, potassium, sulfur and sodium concentrations were gradually increased with the time passes but reduced again in the effluent water towards the end of the study, suggesting that these nutrients extracted by the plants at a higher rate for their growth. However, the phosphorus extraction in later stages was less in comparison to production in the last sampling in August 2014 in the mint tilapia co-production system. But in the strawberry tilapia co-production system, initially, phosphorus concentration was low and with the time passed it was in a peak and later plants consumed and concentration reduced again (Fig. 2). The concentration of hydrogen carbonate, however, increased throughout the experimental period and a significantly higher amount recorded at the end of the study. It was not clear whether plants had used hydrogen carbonate or not (Table 1).

TABLE 2
AVAILABLE NUTRIENTS IN INFLUENT AND EFFLUENT WATER IN MINT BASED TILAPIA VERTICAL AQUAPONICS SYSTEM

Parameters	Influent			Effluent		
	May-2016	June-2016	July-2016	May-2016	June-2016	July-2016
P(ppm)	0.16±0.01	0.93±0.01	1.73±0.03	0.06 ±0.001	0.53±0.002	1.61±0.04
K (ppm)	6.12±0.28	5.27±0.01	5.75±0.14	6.02±0.42	0.84±0.04	4.64±0
S (ppm)	0.49±0.01	4.52±0.30	4.03±0.04	0.27±0.01	3.33±0.25	3.71±0.33
Na (ppm)	64.15±1.4	23.71±0.01	29.4±0	60.0±1.12	23.64±0.06	29.2±0.28
HCO_3^-	219.6±8.63	140.3±34.51	216.55±4.31	253.15±12.94	140.3±8.63	192.15±4.31
CO_3^{2-} (ppm)	0.0	34.5+2.12	0.0	0.0	22.5+2.12	0.0
Total-N (ppm)	4.9±0.99	22.15±0.35	29.4±1.98	2.8±0	17.05±0.35	25.2±0
EC (μs/cm)	662.0±2.83	567.0±1.41	574.5±3.54	666.0±5.66	489.0±1.41	549.5±0.71
Note: Values are given with ± standard deviation						

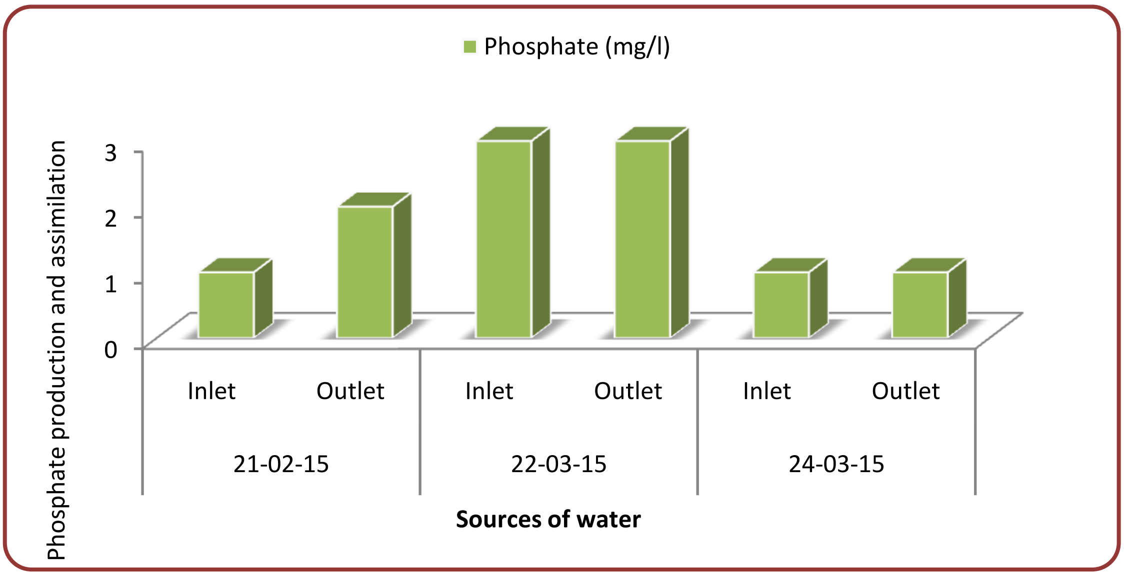

FIGURE 2:Phosphorus production and assimilation in strawberry tilapia based vertical aquaponics system.

In tilapia –mint-based vertical aquaponics system, the fish produced wastes that help as manure for plants' growth and clean water revenues to the fish tank again. The highest value of phosphorus (P) was 1.69(±0.11) ppm in influent, that reduced to 1.19(±0.11) ppm in the effluent water. In the system, 52% P removal was found in the earlier stage of the experiment that was 29.5% at the end. It is distinguished that primarily the P absorption in the influent water was slower in earlier than in later stage and removal was higher. However, in the later stage the P concentration increased and plants absorbed it according to their need that speed up the extraction level higher. Ghaly *et al.* (2005) reported 91.8 to 93.6% P reduction in aquaponics system where they grow barley as a vegetable. Boyd (1998) reported the acceptable P level in aquaponics systems was 0.20-1.15 ppm. Hence, the phosphorous level in the tilapia–mint-based vertical aquaponics system was within the range of the above findings. In addition, the potassium and sulfur concentrations in effluent were higher than in the influent at the beginning of the study. However, at the end of the experiment, when the plants reached maturity, the concentrations of the effluent reduced significantly than the influent concentrations in the system. On the contrary, sodium content was remained static in influent and effluent water at the start of the experiment, nonetheless gradually which decreased with the progress of the study, suggesting that the plants might need a bit of sodium for their growth. The nutrient concentrations in the system were lower than the soil which are generally acceptable for aquaponics as nutrients derived from an excess feed provided to the fish in the tank, and small amounts of nutrients added from the fish feces and mineralization of organic matter (Bittsánszky *et al.*, 2016; Rakocy *et al.*, 2004).

3.2 Fish growth and production

In tilapia based vertical aquaponics system, initial mean length and weight of tilapia were 13.74(±1.77), 22.21(±5.72), 9.06 (±1.22) and 15.26 (±1.41) cm and 51.13 (±22.27), 244.83 (±167.01), 17.27±6.50 and 60.06 (±17.69) g in tilapia based lettuce, strawberry, water spinach and mint vertical aquaponics system individually. During harvest, the highest mean length gained 11.77 (±2.49) with tilapia-water spinach system followed by 5.51 (±0.14), 2.98(±1.05) and 2.95(±.83) g with mint, strawberry, and lettuce VAS respectively (Figs. 3 & 4). By contrast, the highest mean weight gained was 170.38(±78.7) g followed by 114.54 (±28.18), 73.91(±15.95), and 58.92(±52.80) g in tilapia based lettuce, strawberry, water spinach, and mint vertical aquaponics systems.

The highest FCR (2.54) was found with tilapia-lettuce followed by tilapia-strawberry (2.35) system. However, the least FCR found with a tilapia-mint vertical aquaponics system. Ashraf *et al*. (2015) reported FCR of 1.69 and 1.80 for Nile tilapia production in the aquaponics system. Moreover, Azimuddin *et al*. (1998) reported FCR of 1.73 to 2.04 for tilapia fed formulated feed. The above findings are more or less match with the present study. Besides, the highest fish survival was 98.33% found in mint-based vertical aquaponics system followed by 96% with the tilapia-lettuce system and the lowest survival was found with Tilapia Strawberry vertical aquaponics system. The highest fish production (135.2 MT/ha//90 days) was with mint based vertical aquaponics system trailed by tilapia based water spinach vertical system where production was 134.3MT/ha/116 days but if we consider the duration of production then we can see tilapia-mint based vertical system produced 135.2MT/ha in only 90 days.

FIGURE 3:Tilapia based lettuceinVAS

FIGURE 4:Tilapia based Mint inVAS

The lettuce production was the highest (107.89 MT/ ha/116 days) in tilapia lettuce based vertical aquaponics system, followed by 46.08 MT /120 days and 83.91 MT / 116 days' strawberry and water spinach. Moreover, the lowest vegetable production was 12.47 MT mint/ha/120 days (Table 3). The vertical farming systems (VFS) increase crop production into vertical dimension and not horizontal to achieve a higher revenue using less area (Hochmuth and Hochmuth, 2001; Resh, 2012). Moreover, yield increases about 129–200% in VFS and a profit increase of 3.6–5.5 US dollar/m^2 area compared to traditional soil cultivation (Liu *et al*., 2004). Therefore, we can see the vertical farm offers more opportunities considering the three pillars of sustainability- environment, society, and economy (Kheir, 2018).

In the tilapia-mint based vertical aquaponics system, for a one cm length increase of fish, the weight increased on an average 19.91 g. Tukey's (HSD) test showed significant differences in mean length and weight of fish between few sampling dates but not all the dates. The Coefficient of determination, (R^2 value) was 0.982, signifying that 98% of the variation of the dependent variable (weight) explained by the independent variable (length). The positive correlation (r=0.99) between the length and the weight of tilapia was very high. The mean food conversion ratio in the experiment was 1.50, survival was 98.33%, % length gain 36.11(±9.93), % weight gain 190.71 (±159.29) and total production of tilapia were 135.20 MT/ha/90 days (Table 3). Higher rates of CO_3^{2-} reduction (72.00±6.12 to 36.00±1.12 ppm) noticed in the system in July 2016, while the value increased significantly in the effluent in August 2016. On the other hand, the HCO_3^- level gradually increased over the culture period as plants didn't take up the carbonate at a significant level. A similar result obtained by Salam *et al*. (2014). Rahmatullah *et al*. (2010) and Quagrainie *et al*. (2011) reported FCR of 2.69 and 3.10 in tilapia rearing in aquaponics system and pond condition.

The lowest total-N removal from the influent was 23% in the present study (4.20±1.15 to 3.20±0.15 ppm) observed in July, because the highest removal from the system was 50% in August. Ghaly and Snow (2008) reported 76% of total-N removal with Arctic charr (*Salvelinus alpinus*) based aquaponics system and Endut *et al*. (2011) stated NO_3-N removal of 79.17% and 87.10% after 4 and 12 week for the water spinach system, all the above findings were higher than the present findings.

The EC is the measurement of electric current moves through the water. The current can only move through water when there is some salt dissolved in water, but cannot move through pure water. A greater amount of salt dissolved in the water, higher EC and higher nutrient concentrations in water result in superior growth of plants (Pantanella, 2012). The EC value decreased in the effluent throughout the culture period. The highest EC value was 598.00(±37.17) μc/cm in inlet water, which reduced to 338.00 (±31.21) μc/cm in the outlet that means removal was 56.52%. Kim (2018) mentioned that vegetable types control the water quality and he found 523±18, 832±43 and 912±52 EC in tomato, basil and lettuce based aquaponics system. The current results are evidence of nutrient removal from the fish tank water used by the mint for their growth.

In the tilapia-water spinach based vertical aquaponics system, tilapia reared for 116 days in a 750-liter plastic water tank where mean length gain was 11.77(±2.49) cm and mean weight gain was 170.38(±78.7) g at harvesting (Table 3). Midmore (2011) reported the mean weight gain of tilapia was 85.39±12.04 g after 180 days of raising which is much lower than the present findings due to the seasonal variation, rearing condition and better feed and feeding regime used in the present study.

FIGURE 5: Tilapia based strawberry VAS

The FCR values were 2.54, 2.35, 2.33 and 1.5 in tilapia-lettuce, Tilapia-Strawberry, tilapia-water spinach, and tilapia-mint based vertical aquaponics systems. Rahmatulla *et al.* (2010) reported FCR of 2.19 to 2.69 in the tilapia based aquaponics system and Watanabe *et al*. (2002) mentioned the anticipated FCR of 1.5-2.0 for table size tilapia production. The FCR of the present study more or less similar to the above mention results but some of the FCR higher might be due to unfavorable temperature, feed loss, and some experimental mistakes. Additionally, specific the growth rate achieved 0.98 g, survival rate 85% and total fish production 134.30 MT/ha/116 days which matched with the findings of Salam *et al*. (2014) where they reported tilapia production of 130 MT/ha/116 days in the vertical aquaponics system.

TABLE 3
GROWTH PERFORMANCES OF TILAPIA BASED LETTUCE, STRAWBERRY, WATER SPINACH, MINT CO-PRODUCTION SYSTEMS

Growth Parameters of tilapia based systems	Lettuce	Strawberry	Water spinach	Mint
Mean Initial Length (cm)	13.74(±1.77)	22.21 (± 5.72)	9.06±1.22	15.26 (±1.41)
Mean Final Length (cm)	16.69 (±2.60)	25.19 (±4.98)	20.83 (±3.04)	20.77 (±1.55)
Mean Length Gain (cm)	2.95 (±.83)	2.98 (±1.05)	11.77(±2.49)	5.51 (±0.14)
Percent Length Gain (%)	21.47	13.43 (± 18.47)	231.29 (±28.10)	36.11 (±9.93)
Mean Initial Weight (g)	51.13 (±22.27)	244.83 (±167.0)	17.27 (±6.50	60.06 (±17.69)
Mean Final Weight (g)	125.04(±38.22)	303.75(±180.6)	187.65(±81.93)	174.6 (±45.87)
Mean Weight Gain (g)	73.91(±15.95)	58.92 (±52.80)	170.38 (±78.7)	114.54 (±28.18)
Percent Weight Gain (%)	144.55(±50.60)	43.95(± 39.28)	1161(±526.8)	190.71(±159.3)
Specific growth rate (SGR)	96.0	0.27	0.98	0.83
Feed conversion ratio (FCR)	2.54	2.35	2.33	1.5
Survival rate (%)	96	78	85	98.33
Fish density /m3	67 (104)	100 (150)	107	80
Fish production (MT/ha)	47.33/105days	30.64/120 days	134.3/ 116 days	135.2/90 days
Vegetable production(MT/ha)	107.89/105days	46.08 /120 days	83.91/ 116 days	12.47 /90 days

TABLE 4
LENGTH (CM) AND WEIGHT (G) MEASUREMENT OF FISH IN TILAPIA-MINT BASED VERTICAL AQUAPONICS SYSTEM IN DIFFERENT SAMPLING DATES

Dates	Length of Tilapia (cm)	Weight of Tilapia (g)
4th June 2014	15.26 (±1.41)^{c}	60.06 (±17.69)^{d}
19thJune 2014	16.09 (±0.96)^{c}	77.39 (±15.95)^{d}
4Th July 2014	16.72 (±1.66)^{c}	83.55 (±28.96)^{d}
19th July 2014	17.21 (±1.59)^{bc}	90.71 (±24.77)^{cd}
4th August 2014	19.04 (±1.59)^{ab}	129.90 (±34.21)^{bc}
19th August 2014	19.50 (±1.66)^{a}	134.50 (±37.55)^{ab}
4th September 2014	20.77 (±1.55)^{a}	174.60 ±45.87)^{a}

IV. CONCLUSION

Vertical aquaponics system proved highly successful in producing vegetables in a small area even from the rooftop. With the shortage of suitable farming land in urban sprawl, rooftops are progressively being seen as a reasonable place for producing food and make the building a sustainable food production unit in the future for cities. Like most of the cities in our country an abundance of fallow rooftop places are prevails. The present experiment used four different types of vegetable tilapia in vertical aquaponics system which performed well; nevertheless, water hyacinth root performed better thanthe coconut coir, coco fiber and brick chips. The system efficiently recycles the fish tank wastewater and uptake nutrients to grow crops compared to the conventional system, therefore, the vertical aquaponics system could potentially help to enhance food and nutrient security and reduce pressure on land resources. In this amazing food growing technology, the fish acts as the powerhouse of vegetable production. Aquaponics already proved as a green, sustainable and eco-friendly food growing technology, hence, vertical aquaponics will be able to feed the 21st century's 8.3 to 9.0 billion people and safeguard the environment for the future generation.

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