Building Aquaponic Systems Using Locally Available Materials and Comparison of Productivity between Two Different Systems

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by

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ABSTRACT

The main goal of this research was to design aquaponic system with recycled materials that is environment-friendly as well as design with commercial products to compare vegetable and fish production between the two systems. Through this research we aim to encourage people to produce organic and nutritious food by their own instead of buying from market. Auaponic help to grow 100% organic vegetables that are essential for our health. The system was design in one of the student residential building on the rooftop to avoid external disturbances to the study. The data collection of production was done every 7 days interval starting from September – December, 2016. The fish was feed with commercial floating feed and 5% of their body weight, 3% in the morning and 2% in the evening. The height of five random vegetable was measured every week from each tub to determine their growth. Likewise, five fishes were caught from each tank to measure their weight after 7 days. But weight of vegetable and length of the tilapia was measured once in the beginning and at the end. The result reveals that the growth of both tilapia and vegetable (Chinese cabbage) has increase during the study period of 90 days. The mean weight of tilapia was 51.7 to 77.8; length has increased from 4.67 to 33.5cm in the end of the study period (week0-week4). Similarly, mean height of vegetable from initial to final week was 54.8 to 76.4cm and weight has increased from 38.83 to 350g. However, there were few external and internal factors affecting the growth of both tilapia and vegetables that cause slight alteration in result but the overall result shows significant growth in both tilapia and vegetable and commercial system has better growth as compared to recycle system. Since, the recycle system was run manually, whereas commercial was run by automatic pump and filtration.

Keywords: Aquaponic, Tilapia, Commercial, Recycle, Food, Production, Vegetable

INTRODUCTION

Bangladesh is bestowed with abundant natural water bodies' and fishes. Most of the people in the country are farmers and dependant on fishing and agriculture. However, due to rapid growth in population agriculture lands are converted to settlements, tourism, and shrimp cultivation. Fish from aquaculture serves as an animal protein for billions of people in the world and sustain peoples' live of 10-12% worldwide. In Bangladesh the demands for fish is accelerating due to increase in population and ultimate consequence in competition in land use for crop production and fish farming.[1] Recently, Food and Agriculture Organization in Bangladesh has focus more on the improvement in fish production as fisheries contributes around 3.74 % to GDP in the country. Along with the fish production crop cultivation can also be done with the help of aquaponics. It is also one of the alternatives for sustainable aquaculture development.[2] Aquaponic is a system build with combination of fishes and plants which have cyclic relationship between them. In this system both plant and fishes are benefited because fish gives fertilizer (i.e. feces) to the plants and plants purifies the water and fresh water is supplied to fish. This system is not only environmental friendly but also aid to produce organic and sustainable food production.[1] This system is extremely helpful to improve the food security and solve the problem of lack of protein sources and vegetables consumption due to scarcity in water, poor farming, and shrinkage of land.[2] As aquaponic system required less quantity of water as compared to aquaculture or agriculture farming, moreover it is soilless system. Water loss in aquaponic system is minimum through evaporation and transpiration.[3]

Objectives: To design aquaponic system with recycled materials that is environment-friendly;

To compare the cost and efficiency of recycled materials aquaponic system and commercial system; and

To guide the people to grow their own healthy and organic food using aquaponic system rather than buying contaminated foods from the malls

LITERATURE REVIEW

Food security becomes one of the biggest challenges around the world today. According to World Food Programme 2010, over billion people in the world are undernourished still despite of advance in food production. There are many factors affecting the food security such as dispute, poverty, poor agricultural infrastructure and over exploitation of the resources.[12] Food and Agriculture Organization of the United Nations states, "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. Household food security is the application of this concept to the family level, with individuals within households as the focus of concern."[12]

Agriculture is one of the sources that can meet food security but it consume 70 % of freshwater and some predicted by 2025 it will increased to 90% and it will result in water scarcity. Agriculture depends on soil and improper land use, poor management are some factors resulting in soil degradation. Many people in developing country face the problem of food access as they lack infrastructure like road, insufficient supple etc.

Consequently, in order to prevent or solve the problem of global soil degradation, over-exploitation of resources, poverty and increase sustainable farming practice the possible alternatives are:

Aquaponics: The combination of hydroponic and aquaculture is called Aquaponic system. In this system fishes cultured in the tank and vegetable grow bed above. The nutrients from feces in the tank will go to vegetable and vegetables absorbed nutrients and purify waste water to fresh water and goes back to fish tank. There is no need of soil and it produces two foods (fish and vegetable) for consumption. This system is very effective and it is a solution to solve food security issues.[12] It has fewer challenges as it requires less water, land and space which are extremely needed for highly populated country and arid region like Barbados.[12]

Aquaculture: Similarly, aquaculture is another alternative for improving food security. It can produce many species since it includes both freshwater and saltwater species such as fish, crustaceans, mollusks, and seaweeds.[12]

Hydroponics: In this system also soil is not required as it is a method of growing plants using water. Here roots can absorb minerals and nutrients from water when the nutrients are added in water. There is no need of pests or any fertilizers as plants can manage its own nutrients level as a result hydroponic can also produce healthier crops.[12]

Furthermore, aquaponic serves as a model of sustainable food production because in this system there is benefit of both fish and plants from each other's waste. They result in poly-culture as aquaponic can give many crop productions. This system not only provides healthy food but also increase local economy and limited wastage of water as it is reusing over and over again through the process of filtration and recirculation.[13]

The aquaponic has become popular since 1990s and in 1997 journals started publishing and now there are hundreds of mini aquaponics initiatives and several larger initiatives in the world. Moreover, there are numerous small backyard systems and school projects on aquaponics disperse all over the region.[14] In Bangladesh, Food and Agriculture Organization has focus more on fish production through aquaculture-agriculture farming as fisheries sector contributes 3.74% if the country's economy. For sustainable aquaculture, aquaponic system can also be good alternatives for people.[2] In Bangladesh the rapid growing problems are lack of land available due to increase in population, and increases demand for food. So, an aquaponic system is one way to overcome this problems.[2]

MATERIALS AND METHODS

Aquaponic system was built in one of the student residential building rooftop at Asian University for Women (AUW), Chittagong and it was conducted for around 90 days during September to till first week of December. The experimental set up was well exposed to sunlight.

Table 1: Difference between Two Systems

Parameters	**System A**	**System B**
Grow beds	Stone Chips (Natural)	Brick Pieces
Pump	Water supply continuously	Water supply thrice a day
Water Filter	Present	Absent
Aerators	Present	Present

Experimental Setup

There were six systems where 3 were design from commercial materials (A_1, A_2, and A_3) and 3 were from recycled materials (B_1, B_2, and B_3). This means in commercial system the materials used were all purchased from the market and aquarium pump and filter was used to run the system. Whereas, in recycle system, there wasn’t any filter or pump to run the system. The water was manually transferred from fish tank to the vegetable bed. The materials like brick pieces were collected from construction site and washed thoroughly before placing them into vegetable grow beds. In recycle system the water was poured three times a day to the plant but in commercial system the pump was running continuously throughout the day and sometimes turned off at night. The pipes were connected from filter in the fish tank to the vegetable bed having inlet and outlet of water. The fish raise in the tank was Tilapia and there were 20 fishes in each tank and others were kept in two aquariums (control). The food that used to feed Tilapia was commercial floating feed and fed 5% of their body weight, 3% in the morning and 2% in the evening. In each vegetable grow bed, there were twelve plants and the common name of a vegetable is Chinese cabbage, scientific name is *Brassica rapa subsp. Chinensis.* All the six systems and controls were supplied with two aerators per tank to supply enough oxygen for the fishes.

Step 1: Cleaning and Gathering of Materials

Figure 1: Fish Tank

Figure 2: Cleaning of the Fish Tank

Figure 3: Stone Chips (Natural)

Figure 4: Coarse Sand

Figure 1 shows the fish tank that was used to culture the tilapia for all six systems. All of them are of same size and shape. Since this was an oil container in the market it has to be cleaned thoroughly (Figure 2) to eliminate the oil. Otherwise it will prevent the sunlight penetration which is essential for fish. The stone chips (Figure 3) for commercial system (S-A) and coarse sand (Figure 4) were bought from aquarium shops. The coarse sand was added 2-3 inches on top of the both commercial chips (natural) and brick pieces (big) in recycle system (S-B). This was added to make it even and support the plants root.

Figure 5: Brick Pieces (Big)

Figure 6: Brick Pieces Washing

Brick pieces (Figure 5) also should clean thoroughly (Figure 6) to prevent turbidity in fish tank because the dust and other particles will directly goes to fish tank when the water is pour in vegetable bed. The brick pieces were used for recycle system (S-B) was collected from construction sites and it can also be used from nearby beach or any other places where there is brick pieces.

Figure 7: Water Filter cum Pump

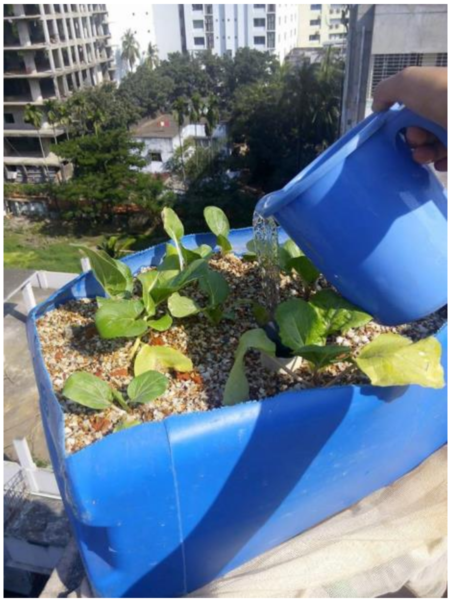

Figure 8: Manual Transfer of Water

The water filter cum pump (Figure 7) was used only in commercial system (S-A) to complete the full cycle of flow of water with feces from fish tank to vegetable bed and from vegetable bed the fresh water will be supply to fish tank. On the other hand, in recycle system (S-B) simple pipe around 2 m long was used to siphon the feces from recycle tank and transfer water by manually to vegetable bed (Figure 8).

Figure 9: Aerators

Figure 10: Air Stones

Aerators (Figure 9) were connected to air stones (Figure 10) using pipe to supply enough oxygen to fish tank. The air stones were attached with heavy materials to keep in the bottom of the tank and as air stone breaks the stream bubbles (Figure 11) coming from the air pump into micro-bubbles, it highly increases the oxygenation in the water.[4]

Figure 11: Aeration of Fish Tank

Figure 12: Cork to Cover the Water Inlet

Figure 13: Water Inlet from Vegetable Bed

A hole was created in vegetable bed to flow water to fish tank when water in the cylindrical shape (Figure 13) was filled. It develops a pressure inside when it was covered by cork (Figure 12) and water will automatically flow to fish tank through the outlet.

Step 2: Building the Aquaponic System

The aquaponic system was design in such a way that it was environment friendly, cost effective and there was symbiotic relationship where both fish and vegetables were benefited each other. The vegetables obtained nutrients from fish feces through the water inlet (Figure 13) in the vegetable bed and fish got fresh water from the water outlet of the vegetable bed (Figure 14&15). There was no use of fertilizers or chemicals for the plants and so it's completely organic vegetables.

Figure 14: Water Outlet from the Vegetable Bed.

Figure 15: Fish Tank with Vegetable Bed

The feces (ammonia) from tilapia were transferred to plants where those were break down by denitrifying bacteria to NO_2 and then NO_3 which were nutrients for the plants and plants use those and fresh water return to the fish again. In that way both plant and fish are benefited at the same time yield organic vegetables.

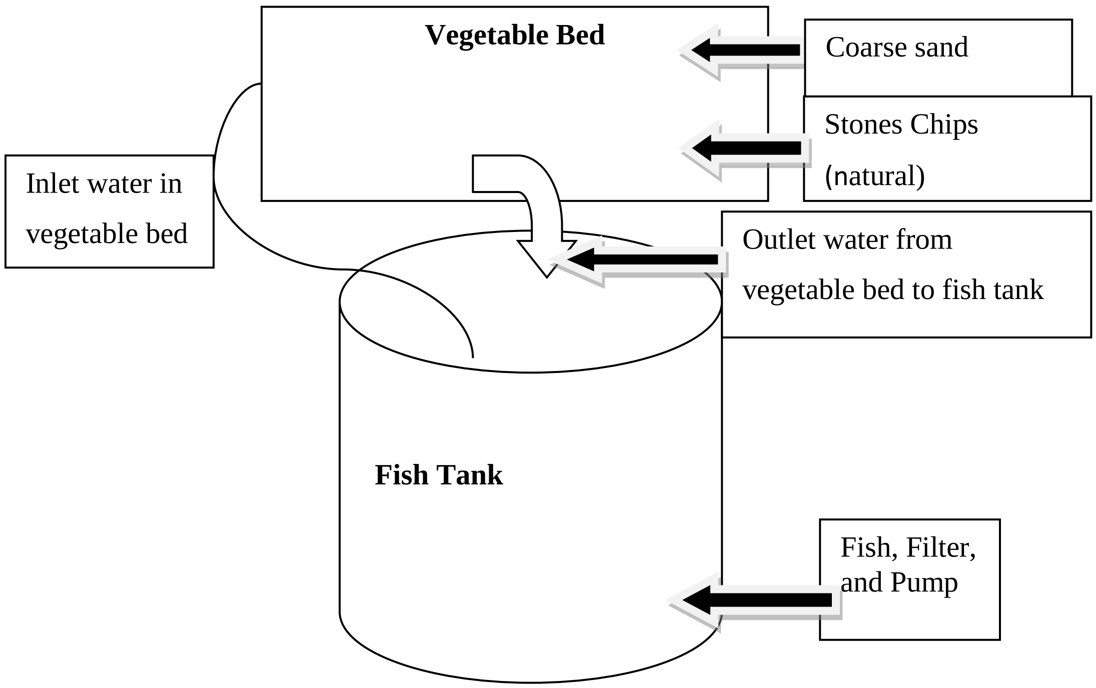

Figure 16: Commercial System (S-A)

Figure 16.1: Aquaponic System A

Here, the system was with continues supply and filtration of water through vegetable bed.

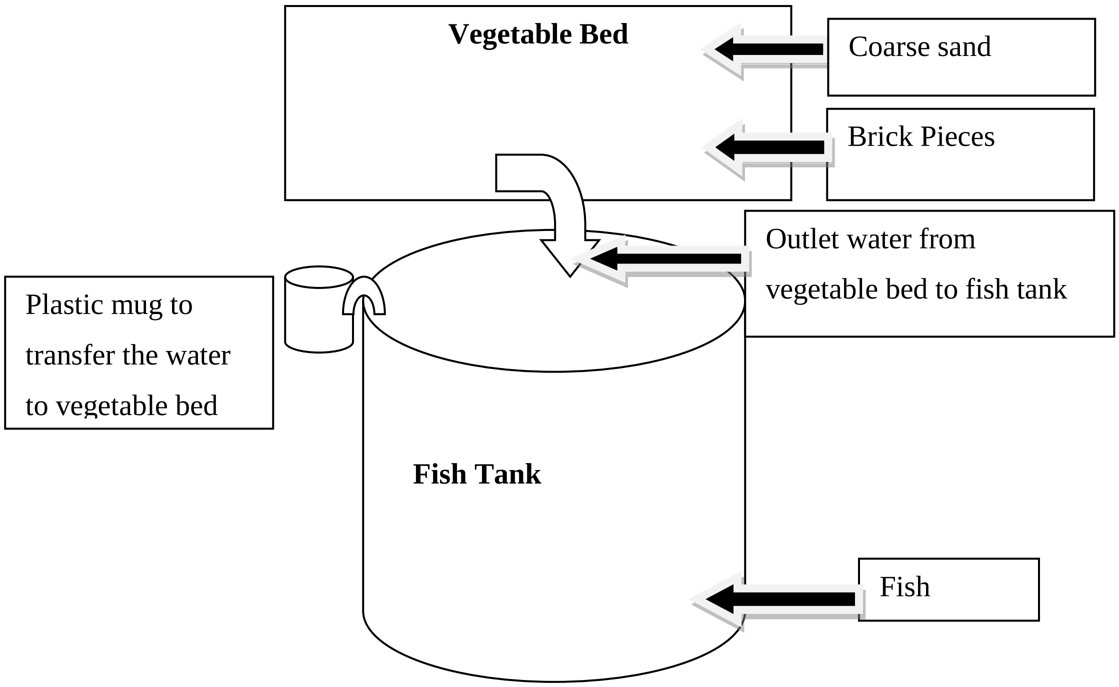

Figure 17: Aquaponic System B

Figure 17.1: Aquaponic System B

Here, it was non-continues supply of water but water was transferred thrice a day using the plastic mug.

Step 3: Data Collection

Figure 18: Weight Measurement of Harvested Vegetable

Figure 19: Length Measurement of Harvested Vegetable

Figure 20: Weight Measurement of Aquaponic Cultured Fish (tilapia)

Figure 21: Length Measurement of tilapia

The weight of Chinese cabbage was measured in the beginning before planting in grow beds and after harvesting (Figure 18) by electric balance. But the measurement of height was done every 7 day's interval. Five plants were selected randomly and measured their length using 30cm scale (Figure 19). Likewise, length of tilapia was measured before releasing in the tank and at the end of the study period (Figure 20). But weight of the tilapia was measured every 7 days interval, five fishes were caught randomly with scoop net and put it together in a polythene and weighed on electric balance (Figure 21).

Data Analysis

Fish and vegetable production was analyzed using Microsoft Excel 2007. Graphs for were production were analyzed from Microsoft Excel 2007.

RESULT:

I. Production of Vegetable (Chinese cabbage)

The vegetables were harvested after 90 days of study period. It was measured every after a week and weight at the beginning of the study and at the end of the study. During the measurement of its height, five random vegetables were measured from each vegetable bed both in commercial system (S-A) and recycle system (S-B).

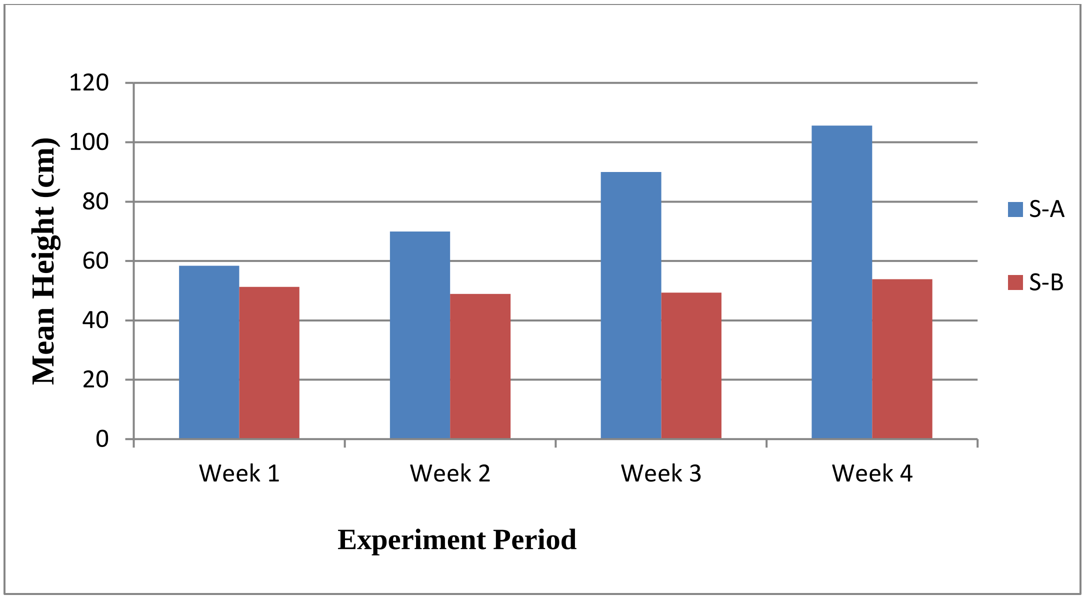

Figure 22: Comparison of growth performance (height) of the vegetables between two aquaponic systems. S-A, Commercial System; S-B, Recycle System

Figure 22 shows the growth of vegetable in two systems from week 1 to week 4. By looking at the graph it is clear that the growth was better in commercial system (S-A) than recycle system (S-B) weekly. The growth in recycle system was not that significant like the S-A.

Figure 23: Chinese cabbage at the Beginning of the Study in S-A

Figure 24: Chinese cabbage at the End of the Study in S-A

Figure 25: Chinese cabbage at the beginning of the study in S-B

Figure 26: Chinese cabbage at the end of the study in S-B

From the above Figure (26, 27, and 28) it is disclose that both the height and weight of the vegetables have increase a lot from initial to final week. But S-B's vegetable growths were not much significant. In S-A, the system was run by pumps and continues filtration so the vegetable also grew well.

Figure 27 (a)

Figure 27 (b)

Here Figure 27 (a&b) displays the difference in growth of Chinese cabbage after harvested at the end of the study in S-A and S-B

II. Production of Tilapia

Tilapia was cultured for 90 days and its weight was measured every after a week but length was measured at the beginning of the study and at the end of the study. During the measurement of its weight, five random tilapia was weighed from each tank both from commercial system (S-A), recycle system (S-B) and control (C).

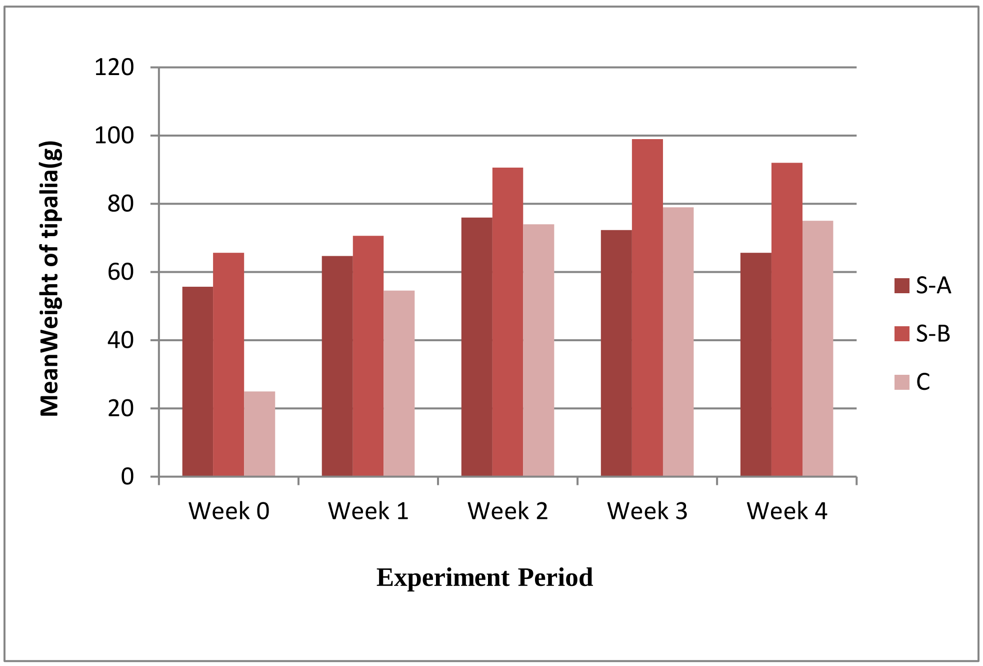

Figure 28: Increment of Tilapia's Weight

Figure 28 illustrates the weight increase of tilapia in two systems and control during the study period of 90 days. Commercial system (S-A) and Recycle system (S-B) both shows there is the increase in weight of tilapia from week zero to week four.

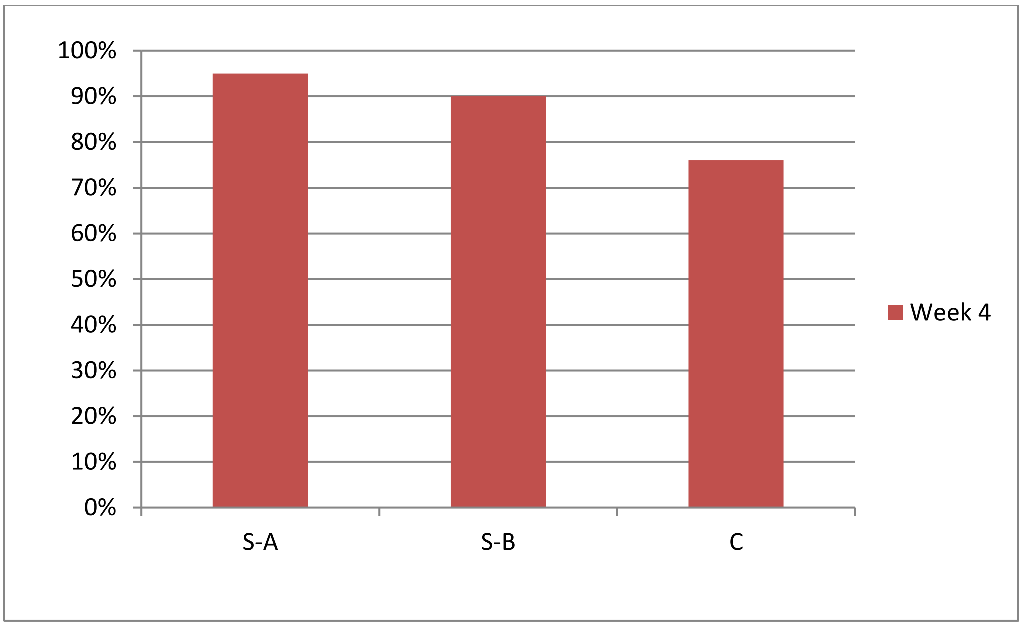

Figure 29: Fish Survival Rate

This figure 29 explains the survival rate of tilapia in both commercial and recycles system and control group in final week of the study. It says that there is decrease of tilapia survival in final week. The death fishes were replaced from week zero till week 3, after that we didn't replace the death fish as it was towards the end of the study period.

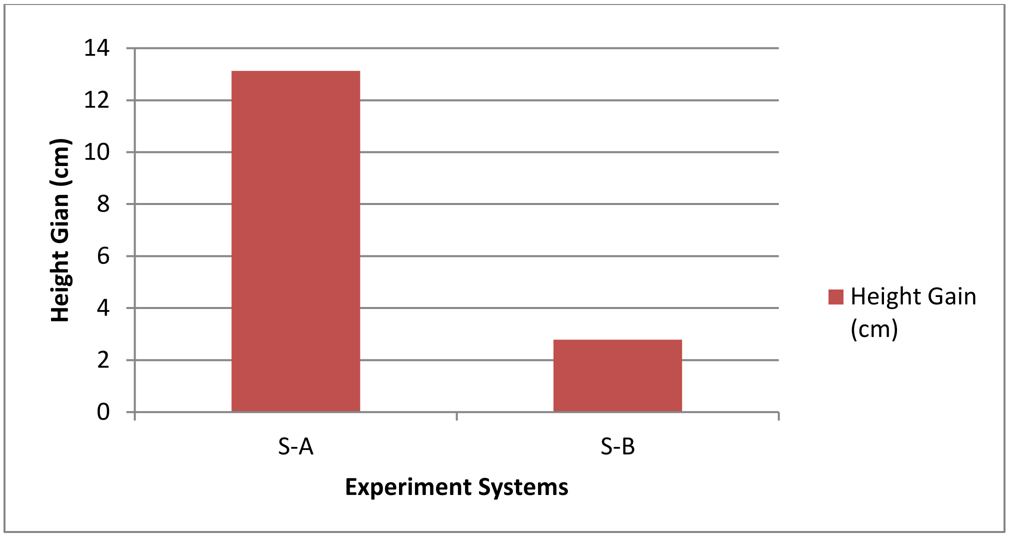

Figure 30: Overall Height Gain of Vegetable

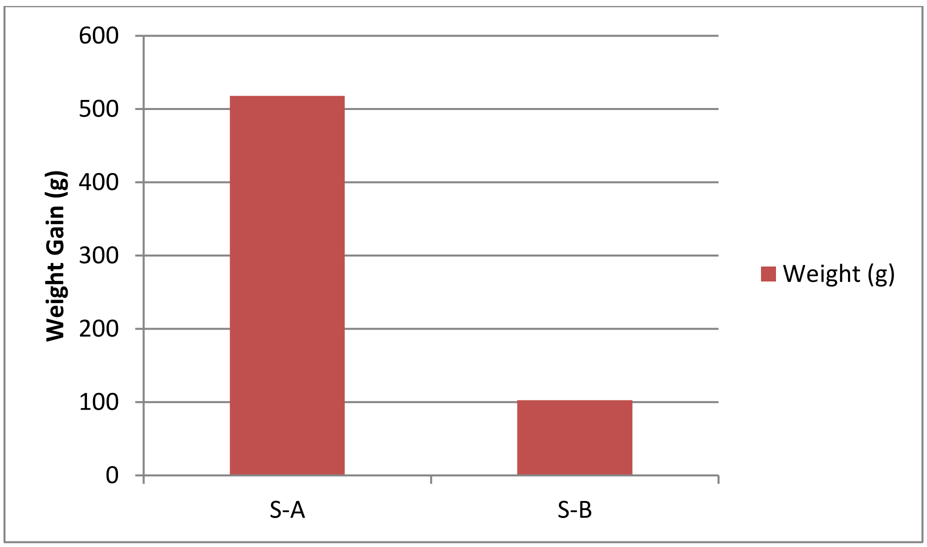

Figure 31: Overall Weight Gain of Vegetable

Figure 30&31 shows the overall growth of weight and height of vegetable both in commercial system (S-A) and recycles system (S-B). The weight of the vegetable in commercial system shows the drastic increase during the study period of 90 days. The height of vegetable is also high in commercial system around 13 cm.

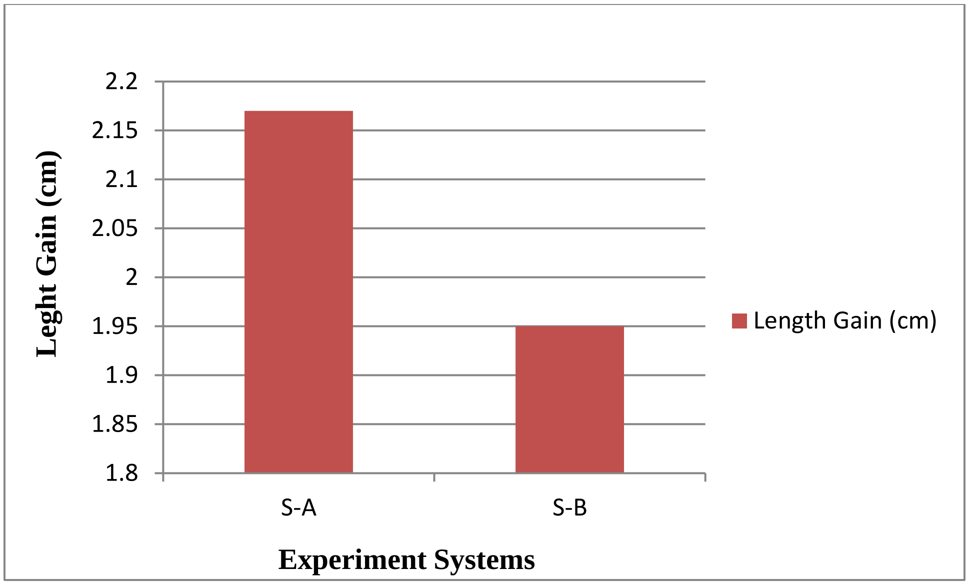

Figure 32: Overall Length Gain of tilapia

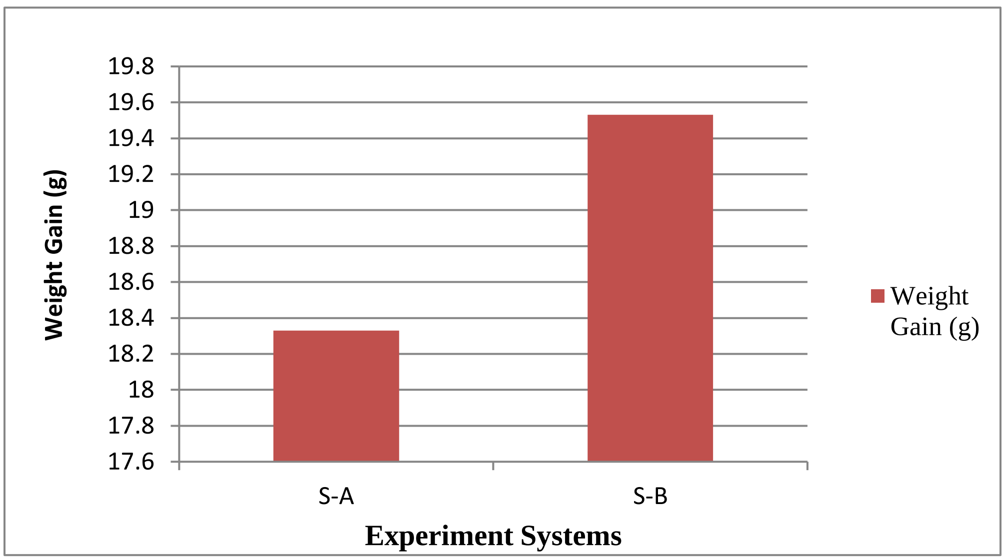

Figure 33: Overall Weight Gain of tilapia

Figure 32&33 shows the overall growth of tilapia in both the systems after culturing for 90 days. Here, the weight of tilapia in both systems has gained their weight almost equal around 18g and 19g.The growth in length of the tilapia is also almost similar in both the systems 2cm and 1.9 cm.

DISCUSSION

The factors affecting growth of vegetables are the medium in which a plant is cultivated. The medium plays a core role in overall growth of vegetable.[7] So, in this research also we have different medium where in recycle system the plant was cultivated on brick pieces from construction sites and in commercial system the vegetables were cultivated on stone chips (natural) from aquarium shop. Although the overall production of vegetables (Chinese cabbage) was significant starting from week zero to week four but when compared between two systems the height of the Chinese cabbage in system A is higher than the system B as shown in Figure 22. In this Figure (22), I didn't include the data of week zero because it was before planting the plants in the vegetable bed so I do not have data of each bed. I have selected randomly five plants of big size, 5 of medium size and 5 of small size and in average it was 13.42cm. Figure 22 shows the height of Chinese cabbage in both the systems from week 1 week 4. In commercial system (S-A) the height increases from 58 cm to 105 cm and in recycle system (S-B) 51cm to 53 cm which is not much significant. The vegetable in S-A has grown well because the system was operated by the aquarium pump and filter where there was constant and continuous supply of water and nutrients, at the same time constant filtration of wastes and all the waste were transfer to vegetable as a fertilizer. Whereas, in S-B there wasn't any technology to run the system and water was supply manually, only three times a day. By the time water was poured to vegetable, in between the waste decomposed and transform to other forms and sometimes the nutrients still remain in the bottom of the tank and vegetable didn't get enough nutrients. Therefore, the growth of vegetables in S-B was insignificant compared to S-A. Another reason is the Chinese cabbage germinates within 5-7days and within 45-55 days it becomes matured. The seeds should be kept moist under the temperature between 15-21^{0}C[5]. In my research, the vegetable was matured only after 80-90days and also the temperature was usually between 25^{0}C-30^{0}C.

Further in Figure 23, 24, 25 and 26 shows the pictorial form of difference in growth of vegetable between two systems as well as growth from first week to final week of the study. The weight of vegetable in recycle system was less than the weight of commercial system because in recycle system's brick piece size were not even and it was much bigger compared to commercial system. According to Aquaponic USA, proper growth of a plant is fulfilled when there is process called flood and drain. This means there should be continues draining and adding of water in grow beds so that roots of the plants will be exposed to the air and get enough oxygen.[6] but, in the system B there was no continuous supply of water, and also the brick pieces were big where the roots couldn't get enough oxygen. Therefore the growth of vegetables in recycle system was hampered and their height and weight was not significant like commercial.

Moreover, pH was found higher in system B approximately 8.9 and in System A approximately 8.6 according to the data collected by Dorji Wangmo who studied on water quality parameters. This was true because in system B while transferring water manually most of the organic wastes in fish tank wasn't transferred to vegetable and it result in higher pH and also vegetable lack the nutrients and didn't grow well like in system A.

Figure 30&31 shows the overall growth (height and Weight) of vegetable in system A and system B e system within 90 days of study period. It shows significant growth both in height and weight of the vegetable in system A because this system was run by continues supply of water and vegetable received sufficient nutrients from the fish tank. All green plants have capacity to produce their own food through of process called photosynthesis. This requires oxygen, carbon dioxide, water and light. In the plant a pigment (chloroplasts) that has chlorophyll helps to trap the energy from sunlight and break down carbon dioxide and create high energy sugar molecules such as glucose. Once the sugar molecules are created it is transfer to all the plants which help in growth, reproduction and metabolism. Even at night plant use these same sugars to produce energy through the process called respiration and this help for the plant to grow.[10] Since both the system was built on the rooftop, the plants were well exposed to sunlight, water, and carbon dioxide. But system B was lacking continue water supply as we supplied 3 times a day which was very less. Thus, it is clear why vegetable didn't grow well like system A. So, plants produce enough food and help in the growth.

For the growth of fish in both the system, one of the factors affecting in his study was tilapia was brought from distant place (2hrs) through so much noisy and traffic jams in a polythene tightly tied by the rubber band. Thus, the fish was extremely exhausted when it reached to our study area. After that we stressed them a little while changing water and measuring length and weight before releasing into the tank. So, after week zero the fishes started dying but we replaced it from the control system. Since it was dying and replacing we can see there is variation in weight of tilapia in (Figure 28). Other factors were water quality parameters such as pH, DO, BOD, TDS, temperature and nutrients (NH_3, NO_2, and NO_3) which was studied by my research partner Dorji Wangmo.

Tilapia is fairly tolerate to wide range of pH and but best pH level should be 6.5-8.5. Dissolved Oxygen in water need to be ensuring adequate otherwise fish suffers from overstock or lack of Oxygen. In the fish tank Oxygen need to be diffused using at least two air stones that will facilitated 5-8 liters of air per minute for each cubic meter of water according to the fish in aquaponics.[8] Absences of oxygen in the water the fish will lose its appetite, surface gasping, reduce growth and become vulnerable to disease.[9] Tilapia requires the temperature between 70-85 degrees F. In aquaponic system the parameters are all interlinked; one parameter affects one or more other parameters. Water temperature has effect on other parameters like oxygen level. Warm water has less oxygen than cold water and in warm water the salinity is more as there will be more unionized ammonia.[9]

Figure 32 shows the increase of average length of tilapia in both commercial and recycle system from week 0 to week 4. However, comparing length growth in tilapia (Figure 32) between system A and system B, we can notice system A shows much higher length than system B. This is because in system B there was no continues filtration and water supply. As it was done manually only 3 times a day, most of the unutilized feeds and feces were not cleaned from the fish tank it result in increase in BOD, Ammonia, Nitrite and TDS. From the result of water quality studied by my friend revealed BOD, TDS and ammonia were high in system B. BOD in system B was 5.01ppm and in system A it was 1.12ppm. Moreover, temperature in system B was found high and it caused decrease in DO level in the system and ultimately impacted the growth of fish in system B.

Overall, the weight of tilapia shown in Figure says it has increase in the entire tank but there were slight variations in some week. According to the "Fish in Aquaponic" article, causes of stress in fish were when the temperature in water was out of the range, dissolved oxygen is too low, ammonia, nitrite or toxins present is high, poor fish handling, noise or light disturbances and poor water quality.[8] From these factors noise pollution has increase towards the week 4 of our study due to renovation work where our systems were installed. Poor fish handling was somewhat true. So, the slight variation in weight growth has due to stress to the fish.

However, the basic needs for tilapia are clean water, oxygen, food, light and room to swim. If these things are fulfilled the tilapia stay healthy and grow fast.[15] So, as we satisfied the needs of tilapia this result in overall growth of both length and weight in both the systems.

For further and better research in future, I compare my data with other's data. The data I am comparing here is "Feasibility of tomato production in aquaponic system using different substrates." This research is done by M.A.Salam, N.Jahan, S.Hashem and K.M.S.Rana, Department of Aquaculture, Faculty of Fisheries, Bangladesh Agricultural University Mymensingh. They have three systems, 1 with gravel mixed with saw dust, system with bricks lets and system 3 with gravels only and it was for 116 days. The vegetable and fish they used are tilapia and tomato. Their result revealed that among three treatments, treatment with only gravels showed highest growth in tomato, the weight is 109.59±116.72 g, 59.66±22.81 and 108.88±69.14 g, respectively in T_1 and T_2. Moreover, the weight and length of fish shows it has increase significantly. Mean length 6.18±0.92 cm which increased to 16.60± 1.18 cm and the mean weight was 5.85±2.30 g that increased to 92.11±18.60 g.[1]

So, the difference I found with this experiment and my experiment was firstly, the duration of the research is more in their case, and they have collected data every after 15 day whereas mine was after 7 days. They have used 3 different medium to cultivate plant but I have compared between commercial and recycle. Moreover, they collected data of height, weight, root weight, no. of leaves and tomato production but I did only with height and weight. They also have water quality parameters.

CONCLUSION:

Overall, height and weight of both tilapia and Chinese cabbage was found to increase from initial to final week of the research duration. However, the growth of vegetable in system B was not as significant as commercial because as it was run manually and water was supplied 3 times a day so plants didn't get enough nutrients and it hindered the growth. Whereas in commercial system there was continues supply of water and most of feces and unutilized feeds from fish tank was given to vegetable and there was significant growth in system A. Other parameters such as pH, DO, temperature, nitrate, nitrite and ammonia were found to be in normal range and suitable for both fishes and vegetables.

Limitations and Recommendations

The duration for this study was limited, thus it has restricted to enhance our reliability of the result. Since designing this kind of system was completely new idea moreover, the places were new for me to gather materials and even recycle materials had to purchase. The crop and fish selection is very important, as researcher wants to match fish and vegetables that have similar requirements for parameters. Many plants can grow successfully in an aquaponic system.[11] Water quality is crucial to aquaponic system. Some 1-5 percent of water is lose from the system through transpiration and evaporation but while replacing good quality water should be used.[11] In order to produce healthy and good production of fish and vegetable, continues filtration and regular water should be supplied in aquaponic system. Other causes of stress are changes in parameters, malnourishment or overcrowding, poor water quality, noise or light disturbances and bullying companions.[8]

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