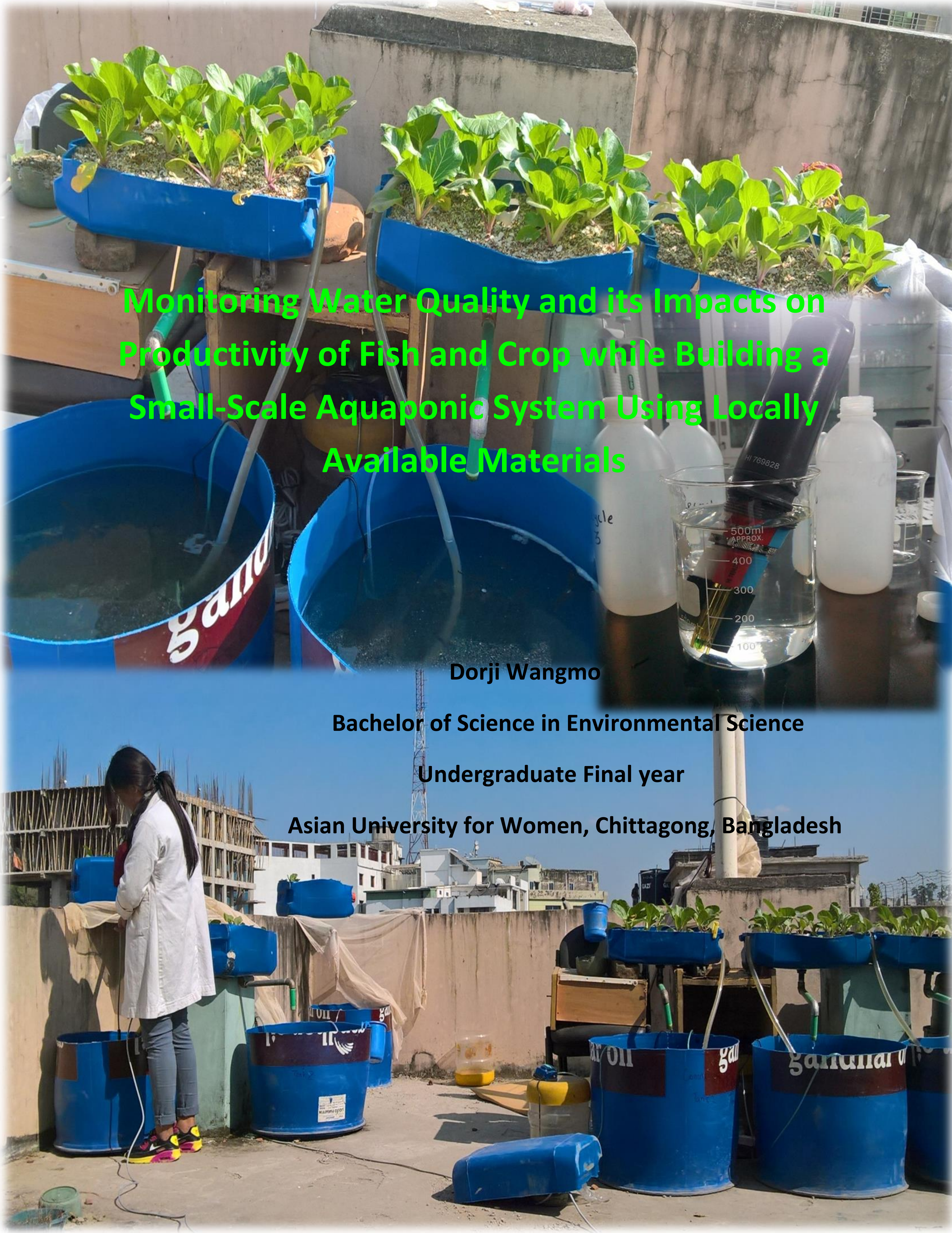

Monitoring Water Quality and its Impacts on Productivity of Fish and Crop while Building a Small-Scale Aquaponic System Using Locally Available Materials

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Bachelor of Science in Environmental Science

Undergraduate Final year

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Senior Thesis submitted for credit requirement for Bachelor of Science in Environmental Sciences at Asian University for Women, Chittagong, Bangladesh

ASIAN UNIVERSITY FOR WOMEN

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AUW120016

Class of 2017

Deadline: 21st January 2017

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ACKNOWLEDGEMENTS

In successful completion of thesis, author would like to express her heartfelt gratitude to thesis advisors, Professor Dr. Harunur Rashid for introducing her to aquaponic idea and giving her opportunity to research on aquaponic water quality topic. Most of all, she is thankful to professor for his kind supervision, constant support and guidance, encouragement and valuable advice throughout the project. Author is also indebted to co-advisor Professor Dr. M. A. Salam for his active support and expert advice in success of thesis. She is also grateful to Professor for his professional feedbacks and editing her work. She also would like to thank Professor A K M Moniruzzaman Mollah for additional encouragement and support and arranging with additional financial support.

This project would not have been possible without financial support from Asian University for Women. So, author would like to express appreciation to AUW for allowing her to do thesis and providing financial support as well as for giving access to AUW laboratory.

She would like to thank Tenzin Wangmo, her research partner for her tireless hard work and effective team work throughout the research. Without her flexibility and cooperation, this research would not have been successful. She is also grateful for Mr. Shawon Baura for his assistance in laboratory work and arranging Test Kits and reagents. She also thanks gardener baiya and plumber baiya for helping with aquaponic system set-up and cleaner apus for helping in taking research materials to rooftop. She thanks to her friend Karma Pema Wangmo and Thinley Wangmo for providing their helping hand whenever needed. Lastly, author would like to thank each and every individual who are directly or indirectly involved in this research.

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ABSTRACT

Aquaponic is a combination of aquaculture and hydroponic system. It is natural and sustainable food production cycle where wastes released by fish is converted into nutrients (ammonia to nitrite and nitrite to nitrate) and used by the plants. The system has economic values and it provides cost-effective and environmental friendly alternatives for wastewater treatment as well as land reduction. In recent year, aquaponic has become popular in many parts of the world because it is cheap and safe food production systems which produce organic and healthy food crops. To maintain a healthy aquaponic system, it requires a regular monitoring of water quality as water is major growth medium and one of the most important factors that affects the functioning of aquaponic system. Therefore, this study was basically aimed to monitor the safe level of aquaponic water quality for effective and sustainable food production.

Keywords: Aquaponics, hydroponics, DO, BOD, pH, TDS, temperature, ammonia, nitrate, nitrite

INTRODUCTION

Aquaponics system is the integration of aquaculture (growing fish) and hydroponic (growing plants without soil) crop production. The aquaponic system creates a symbiotic relationship (Yamamoto and Brock, 2013) where waste (mainly ammonia) generated by fishes are taken up by bacteria and converted into nutrients which is then used by plants. In turn, plants filter water and recycle back clean water to the fish, so water can be use again and again (Filep *et al*., 2016) in a recirculation without requiring to replace with new water. In this way, very little quantity of fresh water is used by aquaponic system comparing to other system such as aquaculture and hydroponics and the only water lost is through evaporation (Filep *et al*., 2016). And also, it is a cost-effective and environmental friendly alternative for wastewater treatment through consumption of nutrient rich water by plants (Gjesteland, 2013). Aquaponics technology has been recognized since 1980s in US and later in many parts of the world (Yamamoto and Brock, 2013). It has become growing interest in recent years due to its range of applications as well as most people are looking for environmental friendly (organic or pollutant-free) system (Sallenave, n.d.). There are also people who practice aquaponic activities as their hobby, some run for business purposes and some develop system for household consumption (Bsc Horticulture, 2007) in small scale production. And also, with decreasing of the farming land, aquaponic system has become one of the alternatives for the growth of plants and fish. The aquaponic system do not required large area of land, it can be installed in-doors especially on roof top, back yard, corridor, and green houses. As installed in-door, the system is resistant to various natural hazards such as temperature, drought, wind, rain and seasonal changes (Yamamoto and Brock, 2013). Hence, aquaponic is one way of natural and sustainable food (fishes and crops) production cycle which can produce food in small scale as well as in large commercial scale (Yamamoto and Brock, 2013). It is also famous for producing 100% chemical free food products for human consumption. The system do not uses pesticides, antibiotics and other chemicals which pollutes the environment. It uses only fish waste and freshwater as growth medium which grows organic vegetables and safe food-antibiotic or pollutant-free fishes. Hence, freshwater is major player in aqauponic system. The system requires special set of water chemistry and optimal water quality monitoring for healthy and balanced functioning of system. It is said that "water is the life-blood of an aquaponic system" (Sommerville *et al*., 2014) because it acts as medium through which all essential nutrients are transferred to the plants and enhance dissolved oxygen for fishes (Sommerville *et al*., 2014). It is also very important for regular monitoring and assessment of water quality of various parameters because poor quality of water is one of the limiting factors that affect the productivity of aquaponics system (Gjesteland, 2013). The system requires elimination of minerals and waste that are build-up in the fish tank which might leads to toxicity or eutrophication. Therefore, in this research, there will be regular monitoring of the water quality to maintain safe level for small-scale aquaponic system and its impact on growth and production of food crops.

OBJECTIVES

The aims and objectives of this research were;

- To assess the environmental parameters of aquaponic system to maintain sound and eco-friendly environment,
- To monitor safe level of water quality of the system for better and sustainability of food production,
- To study the impact of water quality on productivity of crops and fishes,
- To determine the relationship between nutrients generation by fish and growth of plants and
- Lastly to develop a wastewater treatment protocol through building a small-scale aquaponic system.

LITERATURE REVIEW

It was said that the term aquaponics was obtained from aquaculture referring to fish farming and hydroponics referring to growing soilless plants. Aquaponic, an integrated system uses fish excrete waste nitrogen to grow various plants with the help of nitrifying bacteria where ammonia in fish waste is converted into nitrite and then to usable nitrate (Gjesteland, 2013). The two types of nitrifying bacteria are ammonia oxidizing bacteria (AOB) which convert ammonia into nitrite and nitrite oxidizing bacteria (NOB) which convert nitrite into nitrate (Somerville *et al.*, 2014). Through nitrification process, ammonia and nitrite which are toxic for food crops are eliminated and favorable nutrients are supplied to plants.

In the aquaponic, each organism (fish, plant and bacteria) has specific optimal range for each parameter of water quality (Somerville *et al.*, 2014). So, it is important to maintain balance ecosystem with water quality parameters for growing fish, plant and bacteria for healthy and better productivity.

Oxygen is one of the most essential element require for all three organisms (plants, fish and nitrifying bacteria) involved in aquaponics for their growth and survival (Somerville, *et a*l., 2014). Plants take up oxygen as nutrients from atmosphere as well as dissolved oxygen from water and oxygen in root system act as medium for metabolic processes for growth (Gjesteland, 2013). DO is the amount of molecular oxygen dissolved in the water and it is an essential for fish in aquaponic system. It is also require for nitrifying bacteria to maintain high productivity. DO have instant and extreme effect on aquaponic system. If DO level is very low in aquaponic water, fish may die within an hour. The DO for all organisms was recommended between 4-8 mg/L, however, tilapia can tolerate DO level as low as 2-3 mg/L but growth can be affected. Below 2 mg/L of DO, nitrification will starts to decrease/stop (Somerville *et al.*, 2014) which will result in high ammonia content in water leading to eutrophication or nutrient deficiency.

pH is also one of the important water quality parameters to determine how acidic or basic the water is and it is defined as negative logarithm of concentration of hydrogen ion of solution/water. The pH scale ranges from 0 to 14. pH 7 is consider neutral, below 7 is acidic and above 7 is alkaline. The pH level has significant impact on nitrifying bacteria and affects the availability of nutrients (Somerville *et al*., 2014). Aquaponic system requires adequate pH for plants, fish and nitrifying bacteria. The favorable pH range in aquaponic is between 6-7 for both plants and fish (Somervillee *et al*., 2014). However, pH tolerance also differs from species to species. For example, the acceptable pH range for Tilapia fish is between 5 and 10 (Yamamoto and Brock, 2013). Plants, on the other hand grows well when pH is below 6.5 and nitrifying bacteria perform its activity well when pH level is greater than 7.5 and stop functioning when pH level drops below 6. pH is also said to be "master variable" because of its effect on other parameters such as ammonia (Sallenave, 2016).

Similarly, temperature is also very important parameter that affects all organisms in the aquaponic systems. For example, favorable temperature for warm water species such as goldfish, bass, catfish and tilapia is 18 to 29^oC and cold water species such as trout prefer temperature between 13 and 18^oC. And tilapia prefers temperature range between 27 to 29^oC for better growth. There will be growth and reproduction drop along with disease occurrence when temperature falls below 21^oC and tilapia will die when temperature drop below 10^oC. For better vegetable production, required temperature range is between 21^oC and 24^oC (Sallenave, 2016). It is said that optimal temperature range in aquaponic is 18-30 ^oC. And also temperature has effect on DO as well as on nutrient levels (Somerville *et al*., 2014).

Recently, aquaponic has become widely used technology in many parts of the world due to its varieties of application. Aquaponic system can reduce the environmental impact of food production. For example, through waste treatment and water conservation, reduction in energy use and land use, and also it produces high crop yield compared to soil-based and hydroponic system (Bsc Horticulture, 2007).

The most of the past researches in aquaponic field were done on the topic of how to design and operate aquaponics system and only few researches were emphasized on details study of water quality parameter of aquaponic. For example, Filep and his colleagues conducted on building of aquaponic system for the commercial production of fish and plants such as herbs, vegetables, salads and ornamental plants. Through building of small-scale aquaponic system, they found out that building of aquaponic system is fairly easy and it does not require advanced knowledge or expert skills. They also found out that building of aquaponic is very cheap and very easy to manage which can be placed on balcony or rooftop of building. Most of all, they mentioned that many food products such as fish meat and plants (herbs, vegetables, ornamentals) can be culture from the system in small scale as well in large commercial scale (Filep *et al*., 2016).

In one of the research, Gjesteland studied the water quality of recirculated water in aquaponic system where he grew commercial lettuce by using wastewater from smolt production. He had measured all important water quality parameters every day and lettuce productivity was analyzed. In his study, he found out an increase of organic matter in the experiment and lettuce was grown very poorly. He believed that poor growth of lettuce was due to high toxic levels of salts and his analysis showed that nutrients were not sufficient for growth of lettuce. He also saw sign of distress and nutrient deficiency in leaves of lettuce. He mentioned that best solution of this kind of problems is to use a plant that is more tolerant to salts. Other research had studied on the use of ornamental fish as a complementary species and the impact of pH levels of aquaponic on the nitrification process (Tyson, 2004). Additionally, Yamamoto and Brock studied on comparison between aquaponic gardening and traditional gardening growth and he found out no significant difference between two system in terms of plant growth (Yamamoto and Brock, 2013). And also one of the researches was done on aquaponic as an alternative for wastewater treatment and human urine treatment and concluded that though aquaculture is possible to treat wastewater and human urine; overall it does not perform as good as recirculating aquaculture systems (Sanchez, 2014).

MATERIALS AND METHODS

Aquaponic system was installed in rooftop of 20J dormitory building, Asian University for Women consisting of six fish tank (175 L), each attached to vegetable tub (50 cm x 30 cm) by metallic tube through which filtered water from vegetable tub is released to fish tank as shown in the Figure 1. The aquaponic systems were divided into two; System A and System B and different components of System A and B are listed in Table 1. Two aquariums was also set-up as a control/treatment group (System C) without connecting to vegetable bed (hydroponic component) to compare parameters variation between experimental set-up (System A and System B aquaponics connected with plants) and control without plants. Chinese cabbage (*Brassica rapa subsp. Chinensis*) and Tilapia (*Oreochromis niloticus)* were chosen to culture in small-scale aquaponic system. The detail of the method was emphasized on the influence of water parameters on growth of plants and fish. Water quality of different parameters (DO, pH, TDS, temperature, BOD, nutrients) were tested every week for five consecutive weeks (week 0-week 4; week 0 is week before releasing fish) in the month of November and December, 2016. Samples were collected from each fish tank as well as from aquariums in 450 ml of opaque plastic bottles and ice boxes were used to carry sampling bottles to the laboratory. Nutrients (ammonia, nitrate and nitrite) in mg/L and BOD (ppm) were experimented in laboratory while other parameters such as temperature (ºC), DO (ppm), TDS (ppt), and pH were measured on-spot where the system was installed.

Figure 1: Aquaponic system installation on rooftop

Table 1: Difference between System A and System B

Parameters	System A	System B
Grow beds	Natural stone chips from shop	Brick pieces from construction site
Water pump	Present (continuous water supply)	No water pump (manually pouring of water thrice a day)
Water filter	Present	No
Aerators	Present	Present

Table 2: Water Quality Parameters Studied

Parameters	Methods/Instruments used
DO	Hanna Instrument (HI) Multi-parameter Meter
pH	HI Multi-parameter Meter
TDS	HI Multi-parameter Meter
BOD	Stored in dark incubator 20^oC for 5 days ($BOD=DO_1-DO_5$)
Temperature	Graduated Celsius Thermometer
Ammonia	HI 3824 Ammonia Test Kit
Nitrite	HI 3873 Nitrite Test Kit
Nitrate	HI 3874 Nitrate Test Kit

Dissolved Oxygen (DO): It is the amount of oxygen (O_2) dissolved in water and is measured in units of parts per million (ppm). DO is one of the most significant parameters in aquaponic system for the growth and survival of fish and it is also vital for nitrifying bacteria that convert fish waste into nutrients which can be used by plants (Sallenave, 2016). DO was measured on-spot using HI multiparameter meter which has multiple sensors connected to main probe. The probe of the meter was dipped into the fish tank as shown in the Figure 2 and recorded when it came to stable reading.

Figure 2: On-spot measurement of DO, TDS and pH using Hanna Instrument Multiparameter Meter

Figure 3: Multiparameter Meter with GPS

pH: The term pH stands for power of hydrogen is also one of the important parameter in determining the health of aquaponic water. It is measure of how acidic or basic the water is and it determines the amount of hydrogen ions (H^+) in the water. pH was measured for all six tanks and two aquariums using multi-parameter meter as same as in DO measurement (see Figure 2).

Total Dissolved Solids (TDS): TDS is a measure of the minerals, metals, ions, or salts contain in the water bodies or basically, it is a measure of anything excluding H_2O molecule in the sample water in the units of parts per million. It is important in aquaponic system as it detect the total organic loads such as minerals and carbonates in the water (Storey, 2015). TDS was also measured in the same manner as DO and pH using the same multi-parameter (see Fig. 2).

Temperature: Temperature is important to consider while checking a health and safe level of aquaponic water. It is an important factor for growth of both plant and fish and it has effect on other parameters such as DO and ammonia level (Somerville, 2014). Air and water temperature were measured with graduated Celsius thermometer and reading was recorded when thermometer showed fixed reading. For air temperature, only one reading was recorded while water temperature was recorded for each tank.

Biological Oxygen Demand (BOD): BOD is the amount of dissolved oxygen required by biological organisms to oxidize organic materials in sampled water during a specific incubation period. Water samples were collected in 450 ml opaque and air tight bottles and stored in dark BOD incubator at 20^{o}C for the period of 5 days after sampling from sites. After 5 days, DO of the water samples were measured by gently pouring in a beaker, using same multi-parameter meter in ppm. Then, BOD was calculated using formula ($BOD = DO_1 – DO_5$) where DO_1 as initial DO reading and DO_5 as DO reading taken after 5 days of incubation.

Figure 4: BOD measurement after 5 days of incubation

Nutrients (a) Ammonia (NH_4-N): It is a measure for the amount of ammonia to determine

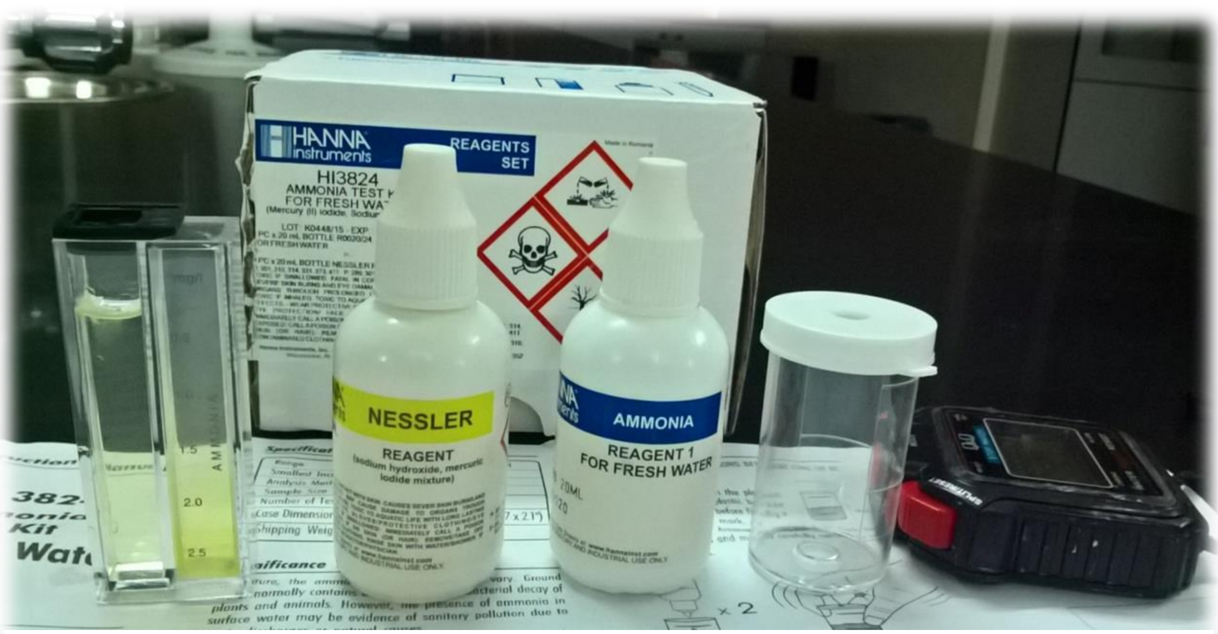

Figure 5: Ammonia Test Kit

health of the water bodies, which is usually a toxic in nature. It is the first form of products released in the nitrogen cycle and measured in units of mg/L. In water, it can present in two states: unionized ammonia (NH_3 or UIA) and ionized ammonia (NH_4^+) where NH_3 is extremely toxic to fish comparing to NH_4^+ (Bowen *et al*., 2011). Ammonia content was measured using HI 3824 ammonia test kit.

(b) Nitrite (NO_2^--N): Nitrite is the second form of product in the nitrogen cycle (Bowen *et al*., 2011) and it is measure in units of mg/L. Nitrite is also toxic but less than ammonia that is released during the oxidation of ammonia by bacteria. Nitrite content of sampled water was determined by using HI 3873 Nitrite Test Kit.

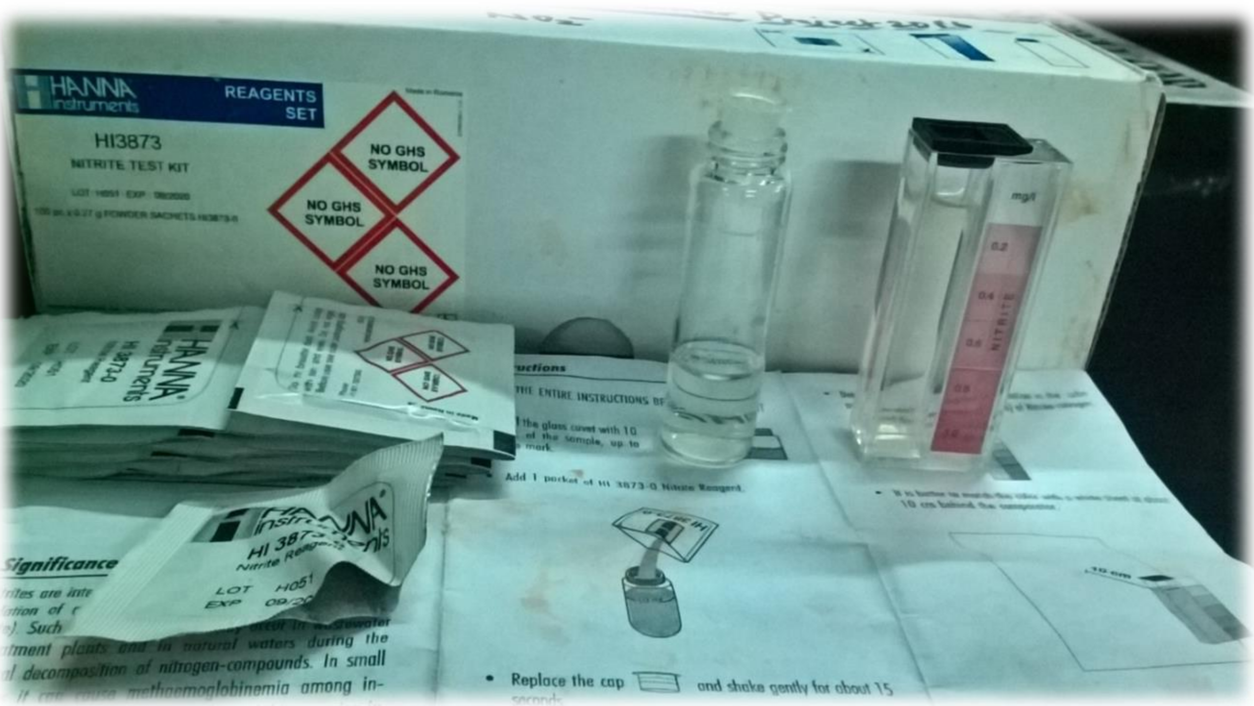

Figure 6: Nitrite Test Kit

(c) Nitrate (NO_3^--N): Nitrate is the last product released in the nitrogen cycle via biochemical oxidation (Bowen *et al*., 2011). Nitrate is not toxic and it is take up by plants as fertilizer. HI 3874 Nitrate Test Kit was used to determine the nitrate content in sampled water.

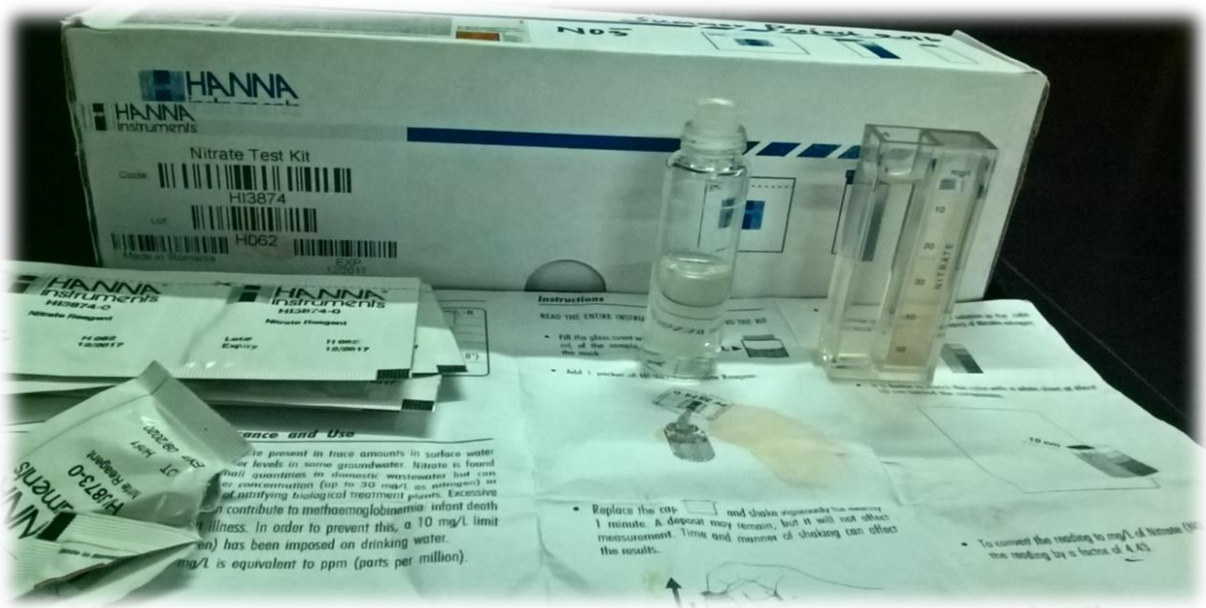

Figure 7: Nitrate Test Kit

RESULTS

Dissolved Oxygen: The highest DO level was recorded in week 3 (01/12/16) in both the System A and System B, 4.71 and 5.01 ppm respectively and the lowest was found in week 0 (10/11/16) with 3.51 ppm for System A and in week 1 (17/11/16) and week 4 (08/12/16) for System B with reading of 3.75 ppm. For control group, the highest reading was 4.78 ppm in week 3 and the lowest was 3.79 ppm in week 4.

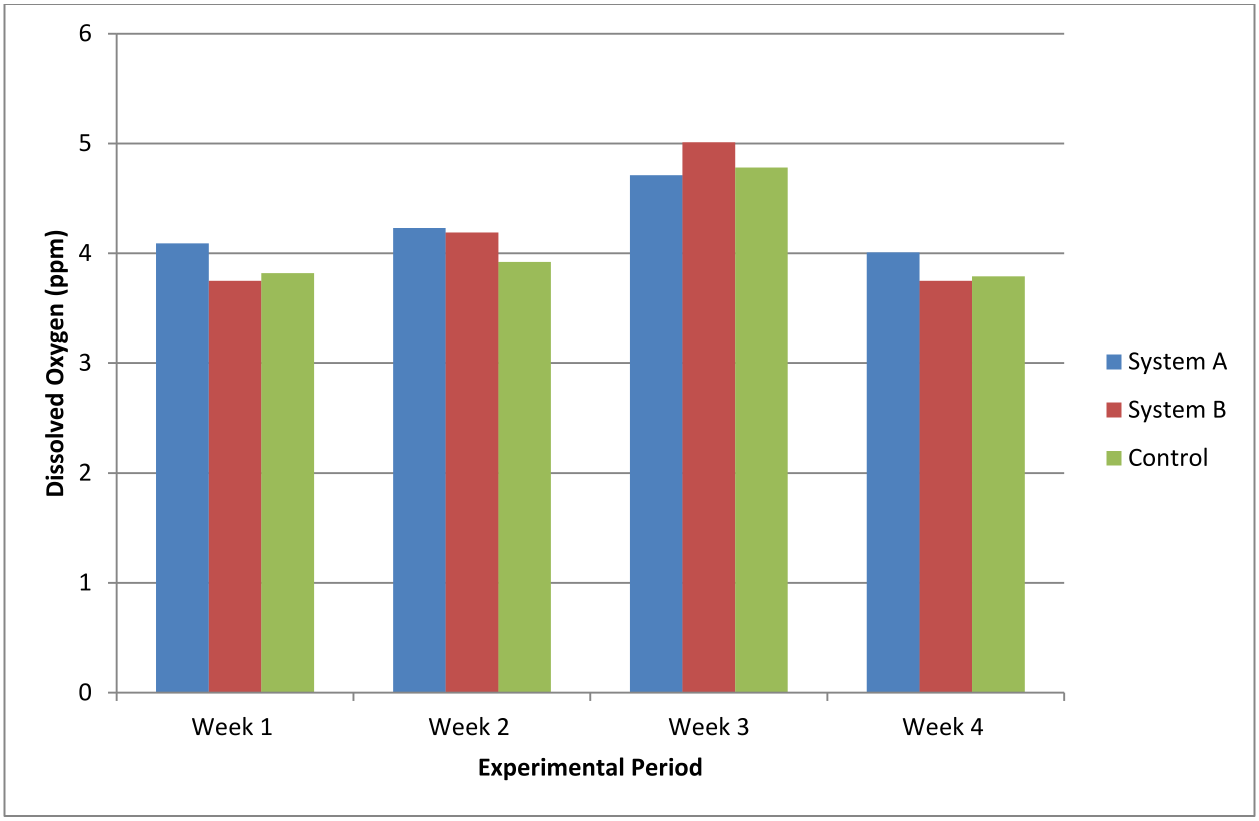

Figure 8: DO measurement in two aquaponic systems and control group. **SA**- continuous transferring of water to vegetable bed using water pump, **SB**-manually transfer of water using plastic mug (3 times in a day) and **C**-system without connecting to vegetable bed.

pH: pH level was found to increase from week 0 to week 3 in both the Systems as well as in control group but it dropped in week 4 in all the Systems including control. pH was higher in System A in week 0 and week 1 comparing to System B but in week 2 (24/11/16), 3 and 4, it was found higher in System B than in the System A.

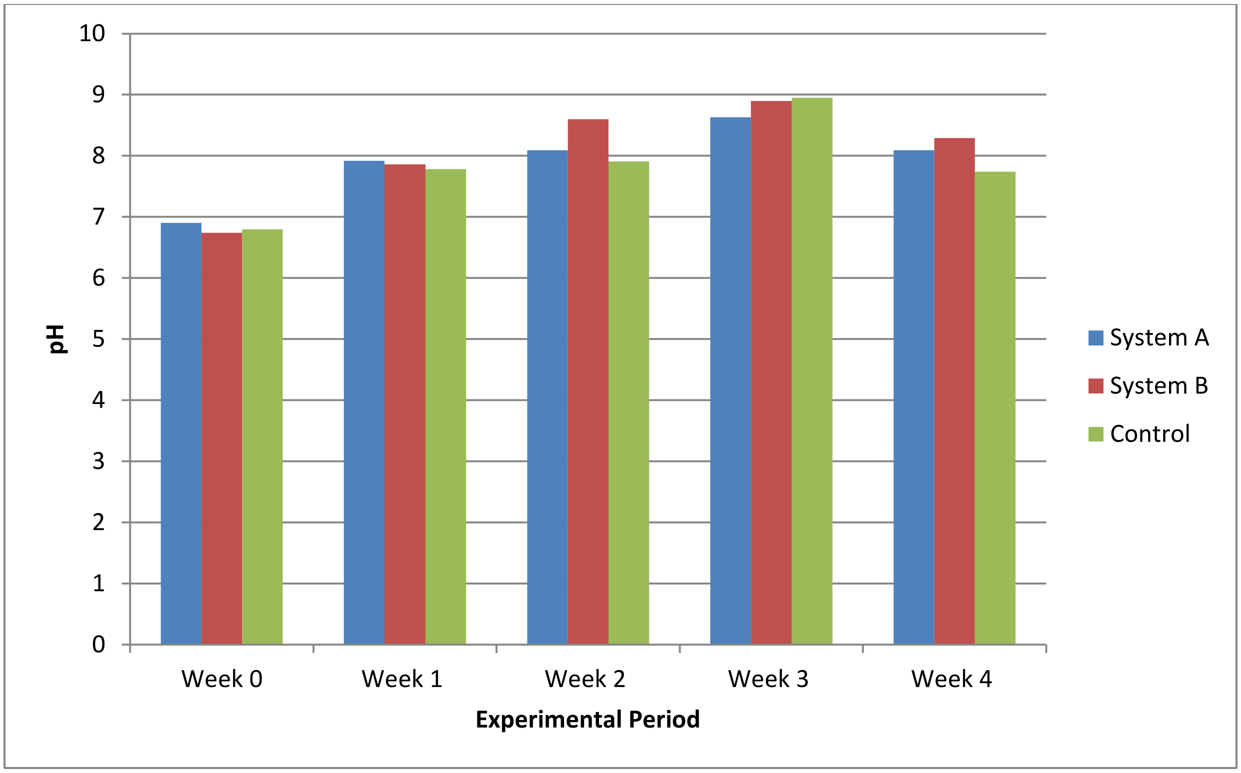

Figure 9: Comparison of pH two systems and control treatment. **SA**- continuous transferring of water to vegetable bed using water pump, **SB**-manually transfer of water using plastic mug (3 times in a day) and **C-**system without connecting to vegetable bed.

Total Dissolved Solids: TDS was found to increase in both the Systems A and B from week 0 to week 3, however, it decreased in week 4. In control group, TDS was found to increase from week 0 to week 1, then drop in week 2 and again increase in week 3 to week 4. TDS was found higher in System B than in System A throughout the weeks except in week 0.

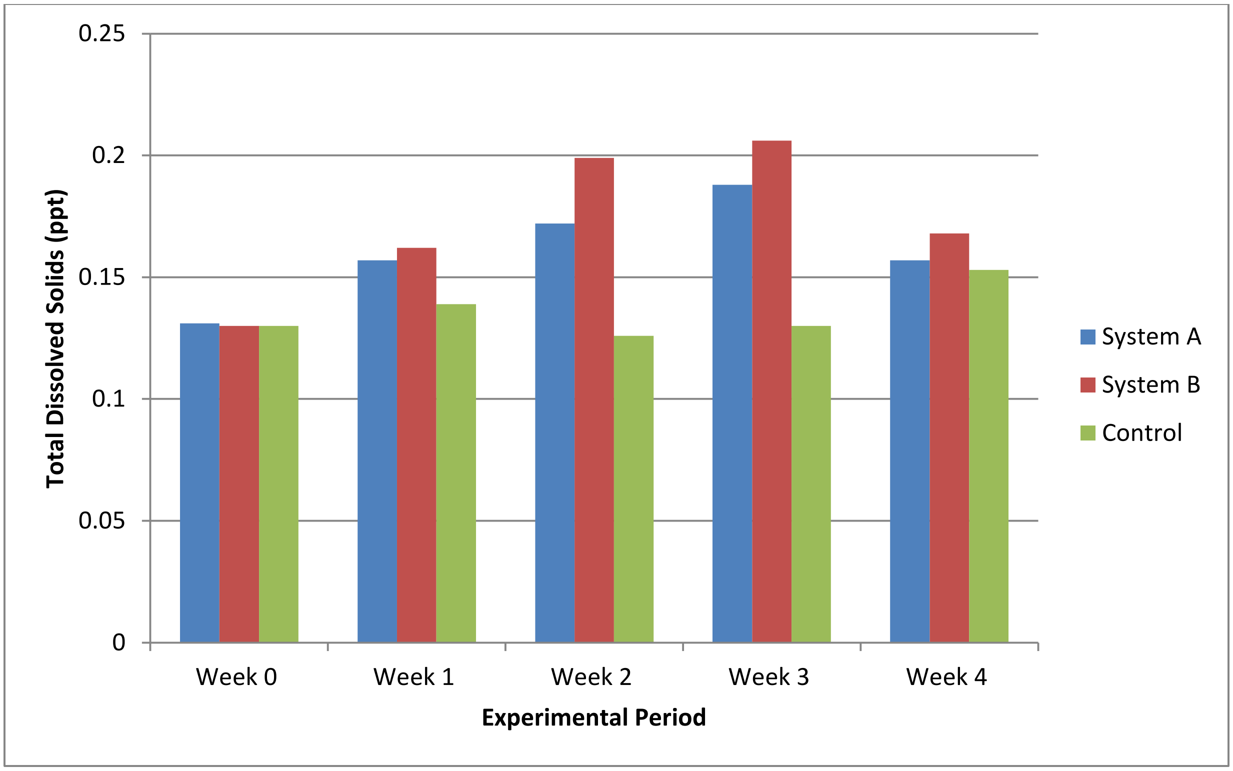

Figure 10: Comparison of TDS between two systems and control treatment. **SA**- continuous transferring of water to vegetable bed using water pump, **SB**-manually transfer of water using plastic mug (3 times in a day) and **C**-system without connecting to vegetable bed.

Temperature: Air temperature was found to decrease from week 0 to week 4 from 29^{o}C to 25^{o}C. The water temperature of the System A was found to decrease from week 1 to week 3 but increased in week 4. And in System B, it increased from week 1 to week 2, then decreased in week 3 and increased again in week 4. In week 0, water temperature was not recorded.

Biological Oxygen Demand: BOD was found highest in the System B (5.01 ppm) in week 3 and the lowest in the System A (1.12 ppm) in week 0. The BOD was found to increase and decrease inconsistently in both Systems but in case of control, it increased from week 0 throughout the week 3 then it dropped in week 4.

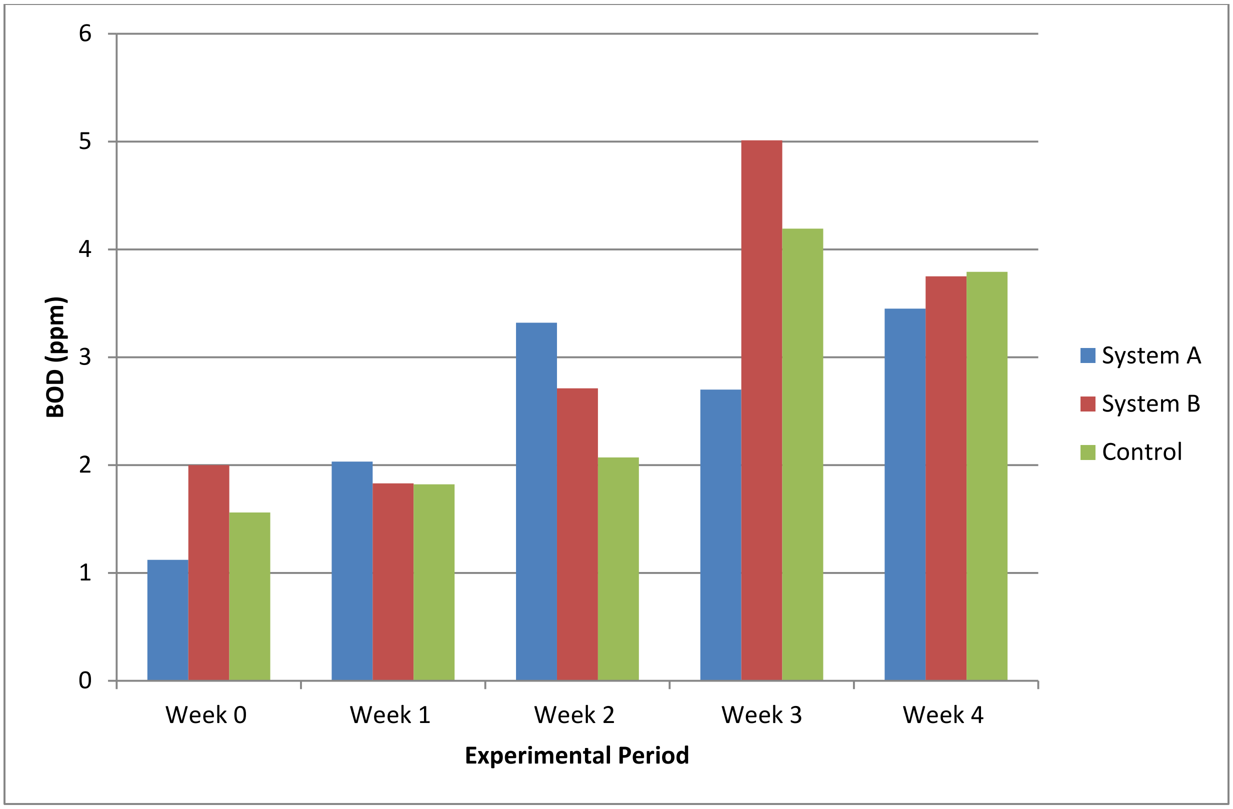

Figure 11: Comparison of BOD level between two systems and control group. **SA-** continuous transferring of water to vegetable bed using water pump, **SB-**manually transfer of water using plastic mug (3 times in a day) and **C-**system without connecting to vegetable bed.

Ammonia: Ammonia content was higher in System B comparing to System A with the highest value of 1.83 mg/L in week 4 and the lowest value 0.33 mg/L in week 0. Ammonia level increases in both the systems but there was dropped in week 2.

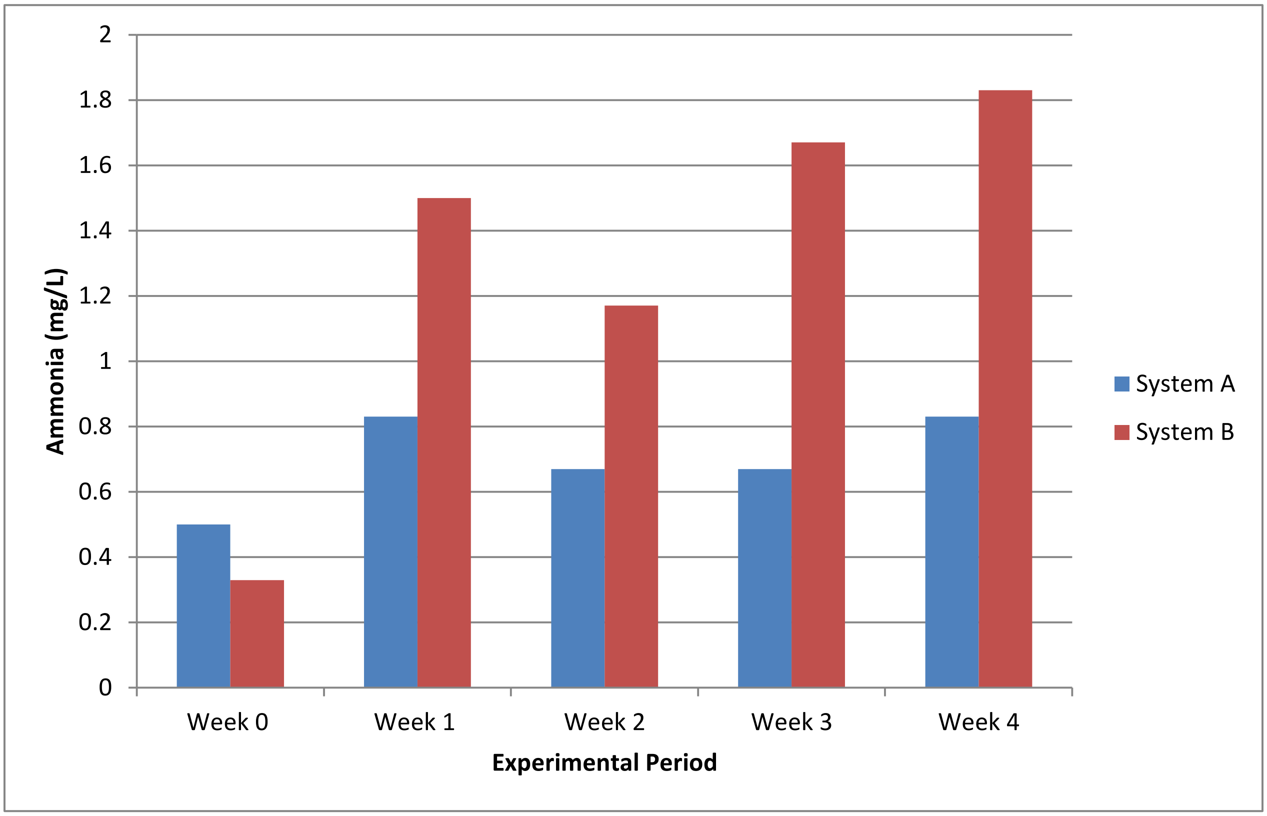

Figure 12: Comparison of ammonia content between two systems. **SA**- continuous transferring of water to vegetable bed using water pump, **SB**-manually transfer of water using plastic mug (3 times in a day) and **C**-system without connecting to vegetable bed.

Nitrite: No nitrite was found in any tanks in both the systems in week 0 and in control, nitrite was not recorded in week 0. However, in later weeks, highest nitrite was found in B-1 system (1.31 mg/L), in some tanks, it was found very negligible (<0.66 mg/L) and some tanks nitrite was not found at all.

Table 2: Nitrite content in each tanks (commercial, recycle, control)

Nitrite	System (A)			System (B)			Control (C)	
	A-1	**A-2**	**A-3**	**B-1**	**B-2**	**B-3**	**C-1**	**C-2**
Week 0 (10/11/16)	0	0	0	0	0	0	-	-
Week 1 (17/11/16)	0.66	0.66	<0.66	0	0	<0.66	<0.66	<0.66
Week 2 (24/11/16)	<0.66	0.66	0.66	1.31	0.66	0.66	0	0
Week 3 (01/12/16)	0	0	<0.66	0.66	0	1.97	0	0
Week 4 (8/12/16)	<0.66	0	0	0	0	0.66	<0.66	<0.66

Nitrate: Nitrate for control was not recorded in week 0. No nitrate was found in week 0, 3 and 4 in any tanks but very negligible amount was found week 1 and 2 in some of the tanks. Nitrate content was found least in System B then control and then in System A tanks.

Table 3: Nitrate content in each tanks (System A, System B and Control)

Nitrate	System (A)			System (B)			Control (C)	
	A-1	**A-2**	**A-3**	**B-1**	**B-2**	**B-3**	**C-1**	**C-2**
Week 0 (10/11/16)	0	0	0	0	0	0	-	-
Week 1 (17/11/16)	<44.3	0	0	0	<44.3	0	<44.3	<44.3
Week 2 (24/11/16)	<44.3	<44.3	<44.3	0	0	0	0	0
Week 3 (01/12/16)	0	0	0	0	0	0	0	0
Week 4 (8/12/16)	0	0	0	0	0	0	0	0

DISCUSSION

Dissolved Oxygen

Figure 8 shows the DO level in the two systems and the control treatment. It shows that DO level in all the systems are below compromised optimal range of aquaponic (>5 mg/L) but DO is within acceptable range for plants that is above 3 mg/L in all three treatments. DO is also not within optimal range for bacteria and fish. In most of the weeks, DO is measured within optimal range for System A comparing to System B and control treatments. This DO variation between systems will result in different productivity of fish and plant. From this, we can tell that productivity will be more in System A comparing to System B. This was proved in the present study and details of productivity comparison between two systems are emphasized in *Building aquaponic systems using locally available materials and comparison of productivity between two different systems* by Tenzin Wangmo who worked on productivity comparison between two systems. She found out that both plant and fish growth was higher in System A comparing to System B. This can be explained that if DO lie within favorable range, more will be the productivity. Reasons for DO level variation between System A and System B can be link with temperature variation between two treatments. It was said that unique relationship between water temperature and DO can affect the food production in aquaponic system. The relationship is; when water temperature increases, DO level decreases due to inability of water to hold DO at high temperature or it can be said that warm water absorbs less oxygen then the cold water (Somerville *et al*, 2014). Temperature was found higher in System B than the System A which leads to decrease of DO in the System B. Temperature increase in the System B can be of placement of systems where System B receives Sun’s heat for longer period.

pH

In Figure 9, pH was found to increase from week 0 to week 3 in all the systems. This increase can be due to increase of organic wastes content in water which was generated by fish. However, there was pH drop from week 3 to week 4 and this can be expected due to action of nitrifying bacteria converting ammonia into nitrate which can be used by plants. pH was found slightly higher in System B than the System A. This means that pH is more basic in System B. The reason can be nutrients coming from fishes were not completely taken up by the plants as water from fish tanks were given to vegetable tub manually by hand but in case of System A, water pump was used which can transport all available nutrients to the plants tub. Overall, pH is found safe and favorable for tilapia as pH level lies within the tilapia tolerance range that is between 5 and10. The pH has impact on growth of plants by controlling access to micro- and macronutrients. At the range of pH 6-6.5, plants can easily get access to nutrients but outside this range, plants cannot take up the nutrients. It was said that pH above 7.5 can lead to nutrient deficiencies (Somerville *et al*., 2014). In this study, pH level is vaguely higher than the average range. This can be expected due to the constant carbonate build up in the system throughout the experimental period and water of pH is being buffered (Storey, 2013). When comparing between System A and B, System A has pH close to acceptable range which can also leads to more productivity in System A than in System B.

Total Dissolved Solids

Dissolved solids are dissolved salts such as sodium, chlorine, magnesium and sulphate which contribute in high residual values in the water. In Figure 10, it shows vigorous TDS increase in both the Systems whereas TDS remain in similar level in control group. This might be due to increase in residues from feeds and fish excreta. In control, water was changed regularly once in a day thus, dissolved solids in water get removed whereas in case of System A and B treatment, dissolved solids were not completely removed or used up by plants as same water was used throughout the study period. The TDS content was more in the System B than the System A. TDS is also linked with other water parameters like DO and nutrients. Higher TDS will reduce the capacity of water to hold DO and it will lower the nutrients take up by plants (Sallenave, 2016).

Biological Oxygen Demand

Simultaneously, BOD was also found in increasing trend. BOD is a measure of amount of oxygen needed by bacteria and other organisms to decompose organic matter present in the water. Increasing trend of BOD means increase in presence of high organic matter in the water which can be oxidized by bacteria and microorganisms. The source of organic matter in the system is from fish waste. As system involves recirculation of water, all the waste are not properly removed or transported to vegetable tub leading to BOD increase every week. It was said that if water contain large quantity of organic matter, there will be lots of bacteria to decompose this organic waste. Thus, BOD will be high but once waste is consumed, BOD level will start to decrease (Palanna, 2009). In Figure 11, BOD level changes in every week in all treatments. In week 0 and week 4, BOD is highest in System B whereas in week 2 and week 3, BOD level is high in System A and in week 4, control has highest BOD level. BOD is also link with other water parameters. For example, when BOD levels are high, there will be decrease in DO because oxygen available in the water will be used by bacteria for decomposition of organic matter (Palanna, 2009) which will then affect the growth of plant and fish because they require sufficient DO to survive. It has also special relationship with nutrients because with the help of nutrients, plants and algae can grow quickly and at the same time die quickly. This contributes to the organic waste which is then oxidized by bacteria resulting in high BOD level. And also increase in temperature will increase BOD level because high temperature will speed up the rate of decomposition of bacteria (Palanna, 2009).

Nitrogen/Nutrients

In an aquaponic system, nitrogen is also one of the crucial water quality parameters which act as a fundamental building block for all forms of life. It is important inorganic nutrients for all plants. The three forms of nutrients in aquaponics are ammonia, nitrite and nitrate. Fish produces waste (feces) that is made of ammonia and this ammonia is converted into nitrite then to nitrate by nitrifying bacteria where plants use nitrate to perform their growth processes. In Figure 12, ammonia level was showed between the two systems. Ammonia level was found higher in System B than the System A except in week 0. This high presence of ammonia indicates the high organic waste (feces) content in the system. As explained earlier, System B involved manual transferring of water to the vegetable bed, as a result all waste build up in the fish tank were not transferred to the plant tub. But in the case of System A, water pump was used to pump out the water which takes along waste in the fish tank to plant bed which lead to removal of waste from the tank. It was said that ammonia level should be as close as 0 (Holdsworth, n.d.) but in the System B, it was recorded more than 1 mg/L. This build up of ammonia in the system indicate that solids are not removed effectively and this might lead to fish death (Holdsworth, n.d.). Possible causes for ammonia increase can be due to excessive feeding or maybe due to insufficient aeration (Sallenave, n.d.). At the same time, nitrite content was given in Table 2. In week 0, no nitrate was found as there was no nitrification process. In week 2, very negligible nitrite was found in System A and control group whereas very, very negligible quantity was found in System B. In week 2 and 3, more nitrite was found in System B than the System A and no nitrite was found in control group. The more nitrite content in the System B is the indication of high ammonia content which was converted into nitrite. However, in week 4, nitrite level decreased in all the treatments. The reason can be either due to decrease in release of waste or all amount of nitrite was converted in usable nitrate.

Similarly, nitrate content was recorded in all the tanks and shown in Table 3. In week 0, no nitrate was found in both the systems and nitrate was not measured for the control group. However, in week 1 and 2, nitrate was found between 0-44.3 mg/L in some of the tanks in both the systems which is within the optimal nitrate range (5-150 mg/L) but again in week 3 and 4, no nitrate was found. The presence of nitrate means nutrients are available for plant but if no nitrate was found then it means the lack of nutrients. Too much (>150 mg/L) or too small (<10 mg/L) quantity of nitrate is not good for growth of plants. If nitrate level is more than 150 mg/L, then water need to be changed and if it is below 10 mg/L, fish feed can be increased to make sure enough nutrients for plants (Samorville *et al*., 2014) and in this case, sometimes plants will fail to make fruits and fish may die (Holdsworth, n.d.). It is also said that excessive level of nitrate is indication of less plants in the system to take up all the nitrates produced by nitrifying bacteria (Sallenave, n.d.). And low nitrate level means not enough nutrients in the system to support growth of plants (Holdsworth, n.d.).

Overall Water Quality

All the parameters discussed have direct or indirect effect on the growth of fish and vegetable. For example as discussed earlier, there was an increase in TDS and BOD level in System B comparing to System A due to built up of organic matters coming from fish. As a result, it lead to decrease in DO level which is essential for fish as well as high amount of TDS and BOD results in deterioration of the water quality in a system. Nutrients is essential for growth of plants, however, too much of nutrients and high temperature result in BOD increase. Also when temperature increases (System B), DO level decreases which then lead to decrease of ammonia conversion into nitrate. This results in low yield of food crops because enough nutrients are not generated for successful growth. Thus, it was found in the present study that both vegetable and fish yield was higher in the System A comparing to the System B. This tells us that aquaponic system is effective and healthier when system is supply with good quality of water and it requires continuous transfer of organic waste from fish tank to vegetable bed for high productivity.

CONCLUSION

Aquaponic is the modern way of producing food crops and it is now found in multiple of application including commercial system, urban farming system and also educational system. It is also major alternatives for wastewater treatment and decreasing land. Aquaponic system is often considered as a food production cycle where aquaculture and hydroponic system is combined together to produced natural and sustainable food crops. In aquaponic, water quality parameters are one of the fundamental factors impacting growth of plants and fish. Thus, the system requires regular water quality monitoring and check up. In this research, after analysis of water quality, it was concluded that some water parameters such as temperature, pH and nitrite level were found within the recommended optimal range however, some parameter such as DO, ammonia, nitrate level were not found within the optimum level. On comparison between two systems, water quality was found healthier in System A which resulted in high productivity of food crops (fish and vegetable). System B was found to contain more organic waste due to irregular transfer of water to vegetable bed unlike in System A which leads to deterioration of water quality and poor productivity of fish and plants comparing to System A. Thus, healthy and continuous supply of water in the system was recommended for better and effective aquaponic.

RECOMMENDATION

- Extend duration of study period for better result; at least 2-4 months
- Use of accurate and standard water testing kits and meters
- Increase testing frequency, twice or thrice in a week
- Follow the optimal range for every water quality parameter depending on the fish and plant species.

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