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# ASSESSMENT OF THE GROWTH PERFORMANCE OF TILAPIA AND TOMATO IN AQUAPONICS SYSTEM

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## ABSTRACT

*This study assessed the growth performance of tilapia (Oreochromis niloticus) and tomatoes (Solanum lycopersicum) in a recirculating aquaponic system. The study was carried out using three culture methods; Fish Culture, Hydroponics, and Aquaponics,* with all the *parameters determined once a week, for 12 weeks. The initial length of the tilapia fish in the fish culture alone was 6.1±0.92cm and increased to 8.4±1.18cm and the mean weight increased from 4.5±2.30g to 8.6±18.60g while the initial length of the Tilapia Fish in the aquaponics system increased from 6.0±0.92cm to 8.7± 1.18cm and the mean weight was 4.5±2.30g and increased to 9.23±0.60g, at the end of the experimental period. There was a significant difference (p<0.05) in length and weight gain of fish. The correlation coefficient (r) was 0.97 for tilapia in an aquaponics system. The correlation coefficient in the experiment indicated that the length and weight of fish were strongly correlated and it was close to 1. The results from the Aquaponics system and ordinary fish culture showed the best growth performance for tilapia. In conclusion, the aquaponics system did not adversely affect the growth of tilapia. The growth of the tomato plant differed when stocked in Hydroponics and Aquaponics systems, the aquaponics system is better than the hydroponics system in terms of growth performance of tomato and tilapia.*

**Keywords:** Aquaponics, Fish Culture, Hydroponics, and growth performance.

## Introduction

Fisheries and aquaculture have proven to play a crucial role as a vital source of animal protein for billions of people worldwide and it supports the livelihood of 10–12 % of inhabitants in the world (FAO, 2012; FAO, 2015), adding a variety to otherwise monotonous diets dominated by starchy staples (Thilsted, 2013). In addition to increased demand arising from population growth, increased demand for protein globally is driven by socio-economic changes such as rising incomes, increased urbanization, and aging populations whereby the contribution of protein to healthy aging is increasingly recognized (Delgado, 2003 and Popkin *et al*., 2012). Compared to meat sources, fish are widely recognized as being a particularly healthy source of protein (Alyssa, et al., 2019). In relation to the world food supply, aquaculture now provides a higher proportion of fish protein than capture fisheries (FAO 2016). This is majorly due to the fact fish is an affordable and most available source of animal protein in the Nigerian diet.

Nigeria remains Africa's largest importer of fish (Oluwarore, 2018). Nigeria's Population Figure in 2015 was 187.3 Million, the total fish demand is 3.25m Mt, and fish production from Aquaculture is 316,727.00 Mt, there is a huge deficit in local production, and only 806,000 Mt tons of fish are imported to meet the annual demand in Nigeria. (NBS, 2017-2018). In the FAO Report of 2009, fish production through aquaculture has increased significantly worldwide and tilapia has become the third most important fish in aquaculture after carps and salmonids. Tomatoes, *Solanum lycopersicum*, is a fleshy vegetable fruit that can be cultivated in big commercial quantities or as a garden fruit. Tomato is a constant ingredient in the preparation of multiple meals in Nigeria. In recent years according to premium times Report, Nigeria has spent over N11 billion on the importation of 65,809 tonnes of processed tomatoes annually, this was confirmed by the Director-General, Raw Materials Research and Development Council, RMRDC, Peter Onwualu, and also Lamido Sanusi, the former Central Bank governor as reported by the prime time newspaper in 2012 and 2013 respectively. However, with the introduction of new breeds of tomatoes that can grow and produce well under the hydroponics system, many farmers have now keyed into large-scale production of tomatoes.

Aquaponics is a technique that combines aquaculture and hydroponic plant production in a closed-loop water system that grows both plants and fish at the same time. The excrement produced by fish in water tanks, which might become poisonous to the fish if not cleansed, is used directly or converted by bacteria into useful nutrients for plants

(Diver, 2006; Malcolm, 2007). As a result, aquaponics is a near-zero discharge system that provides considerable reductions in both environmentally noxious discharges from aquaculture sites, as well as economic benefits from both fish and plant production streams. It also eliminates the problem of nitrogen and phosphorus-rich discharge from soil-based agriculture fertilizers. In decoupled aquaponic systems, aerobic or anaerobic bioreactors can also be used to treat sludge and recover significant macro-and micronutrients in bioavailable forms for subsequent use in hydroponic production (Goddek, and Keesman, 2018).

Nigeria has a high potential to absorb a very substantial fraction of its fish production deficit through fish farming. The country has a huge landmass that is suitable for fish culture coupled with the fact that her high demand for fish and fishery products and its sale price is favorable. Currently, the African continent accounts for less than 1% of the annual total global aquaculture production (FAO, 2012; FAO, 2013) and the vast majority of Africa's aquaculture is in freshwater.

The current production level however needs to be improved to fully achieve the potential production through aquaculture by exploring various production technologies that will help to improve the current performance of the aquaculture industry in Nigeria (Falaye, 1995). The potential benefits of using the aquaponics system to enhance the growing rice and catfish in the Nigeria aquaculture industry have been demonstrated by Nigerian Institute for Oceanography and Marine Research, NIOMR, but further research is needed to determine whether this system applies to vegetable and tilapia (Ikoyo-Eweto, 2020). To achieve this, research on aquaponics systems using aquaculture species to allow for faster growth and more efficient use of feed is needed. After consideration of all the above; Tilapia and Tomato were cultured in an aquaponics system in other to determine the growth performance and nutrient utilization of both Tomato and tilapia as a solution to food security problems in Nigeria. The specific objectives of this study are to evaluate the growth performance and nutrient utilization of tilapia in the aquaponic system; to determine the yield of tomatoes under aquaponics systems and to assess the survival rate of tilapia under aquaponics systems.

## Materials and Methods

The experiment was carried out at the University of Ibadan's Department of Aquaculture and Fisheries Management in Oyo State, Nigeria. The experimental fish used for the study was tilapia (Oreochromis niloticus) while the vegetable was tomato (Solanum lycopersicum). The fish was purchased at 8 weeks old and transferred to the farm where it was measured, fed, and observed before transferring to the aquaponics system, the fish were fed under different conditions for twelve weeks. The tomato seeds used were purchased at Agrotropic Ltd, Ibadan, Oyo State, and were planted in the nursery for 4weeks before transplanting to the aquaponics system and the beds.

### Experimental Procedure

The experimental design for this study was three by two factorial (3 X 2) having 3 treatments with 2 replicates for each treatment, the treatments that were used for these experiments are the aquaponics system, hydroponics system, and fish culture system.

The experimental fish was kept in the aquaponics system and grouped into three combinations representing different treatments as stated below:

Treatment FC - Fish Culture; Treatment HP – Hydroponics; Treatment AQ - Aquaponics

The fish were fed and weighed weekly and the feeding rate was adjusted accordingly with the use of a sensitive scale. The mean average weight, standard length, and total length of the fish in each tank were measured at the start of the experiment and thereafter on weekly basis. A sampling of fish for measurement (body length) was done using the 30 cm meter rule and the weight was determined using a sensitive scale (Ohaus Ranger R31P30). All fishes in each tank were measured separately.

### Evaluation of Water Quality Parameters

Water temperature, pH, and dissolved oxygen (DO) concentrations in water were monitored twice a week except for ammonia and nitrate which were monitored once a week. The temperature was measured using a mercury-in-glass thermometer. pH was measured with a pH meter (Hanna model H1-98107, Beijing 100081, China), and dissolved oxygen with the Winkler method (Viveen *et. al.*, 1986; Boyd, 1990). Ammonia and nitrate were determined in the laboratory as described by Boyd and Tucker (1998).

### Growth and nutrient utilization parameters

Growth and nutrient utilization parameters were assessed in terms of Mean Weight Gain (MWG), Specific Growth Rate (SGR), Percentage Weight Gain (PWG), Mean Growth Rate (MGR), Feed Conversion Ratio (FCE), and Survival Rate (SR), using the following formulae below as used by (Pechsiri and Yakupitiyage, 2005; Akinwole and Faturoti, 2006):

**Mean Weight Gain (g):** was calculated as the difference between the initial and the final mean weight for fish in each tank.

**Specific Growth Rate (SGR):** was calculated from data on changes of body weight over a given time interval;

$$SGR = \frac{100 \times (1n\ FBW - 1nIBW)}{D}$$

Where: FBW = final body weight (g) (weight at the end of the time interval studied)

IBW = initial body weight (g) (weight at the beginning of the time interval studied)

D = number of days

**Mean Growth Rate (MGR):** These was computed using the standard equation:

$$MGR = \frac{W2 - W1}{0.5(W1W2)} \times \frac{100/t}{1}$$

Where: $W_1$= Initial weight
$W_2$ = Final weight
t = Period of experimental days
0.5 = Constant

**Relative Growth rate (RGR)**: These was calculated as:

$$RGR = \frac{Weight\ gain\ by\ fish}{Initial\ body\ (g)\ weight} \times 100$$

**Percentage Weight Gain (%WG):** This is expressed by the equation:

$$PWG = \frac{Wt - Wo}{Wo} \times \frac{100}{1}$$

Where: Wo = Initial weight

Wt = Weight at time t

**Survival Rate (SR):** The survival rate SR was calculated as total fish number harvested/total fish number stocked expressed in percentage.

$$SR = \frac{Total\ fish\ number\ harvested}{Total\ fish\ number\ stocked} \times 100$$

Mean Weight Gain (g): This was calculated as the difference between the initial and the final mean weight for fish in each tank.

## Results

### Water Quality Parameter

The results of the water quality parameters taken during the period of the experiments were recorded as shown in Table 1 with the following average values for $NH_3$ (4.5±0.55); $NO_2$ (1.0 ±0.35); $NO_3$(42.2 ±10.77); pH (7.5 ±0.08); DO (4.0±0.85 ppm) and Temp (28.8±0.33°C) respectively

**Table 1: Water quality parameters of fish reared under different culture systems**

| | FC1 | FC2 | AQ1 | AQ2 |
|---|---|---|---|---|
| **TEMP** | 28.8±0.33 | 28.4±0.29 | 28.3±0.33 | 28.2±0.26 |
| **pH** | 7.5±0.08 | 7.4±0.07 | 7.5±0.08 | 7.8±0.14 |
| **$NH_3$** | 4.5±0.55 | 4.6±0.60 | 1.7±0.80 | 1.8±0.78 |
| **$NO_2$** | 1.0±0.35 | 1.0±0.41 | 0.6±0.22 | 0.7±0.34 |
| **$NO_3$** | 42.2±10.77 | 42.5±12.21 | 26.9±9.35 | 26.9±9.35 |
| **DO** | 4.0±0.85 | 3.8±0.94 | 6.0±1.02 | 5.9±0.95 |

The average $NH_3$, $NO_2$, $NO_3$, pH, DO and temperature values for the aquaponics system were 1.7 ±0.80, 0.6 ±0.22, 26.9 ±9.35, 7.5±0.08, 6.0 ±1.02 ppm and 28.3±0.33°C respectively. (Fig.1) There were significant ($p<0.01$) differences in temperature on different dates, however, no significant differences among the pH and DO values were found within the fish culture and aquaponics system.

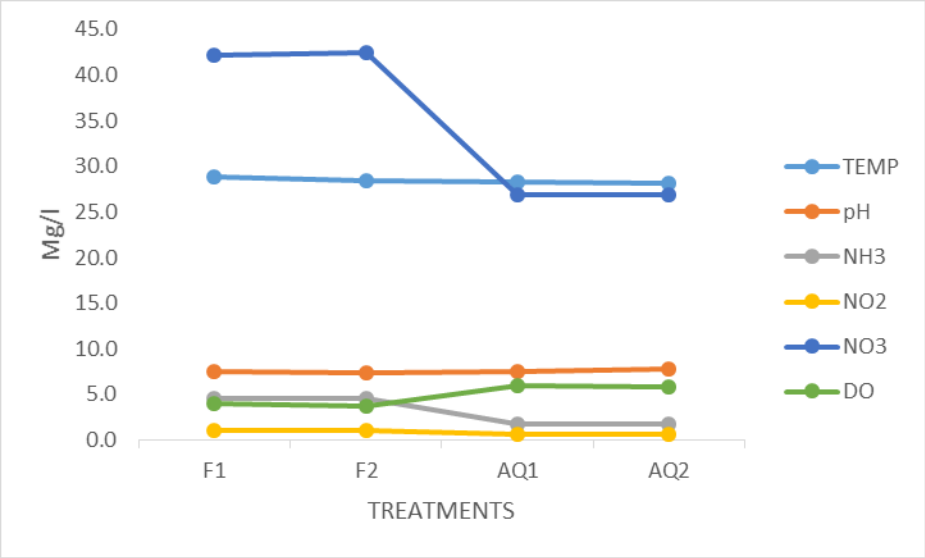


**Fig. 1: Water quality parameters of fish reared under different culture systems.**

Fish Culture 1 (FC1) had the highest temperature value (28.8±0.33 ºC) while Aquaponics 2 (AQ2) gave the lowest value (28.2±0.26 ºC). The concentrations of dissolved oxygen (DO) varied from 3.8±0.94 mg/L to 6.0±1.02 mg/L. There was no significant difference in DO levels of fish reared in all aquaponics systems. However, the DO level was lowest (3.8±0.94 mg/L) in Fish Culture 1 (FC1) and highest (6.0±1.02 mg/L) in Aquaponic 1 (AQ1). For pH, the maximum value (7.8±0.14) was realized in Aquaponics 2 (AQ2), while Fish Culture 2 (FC2) achieved the lowest value (7.4±0.07). Nonetheless, there is no significant difference (P>0.05) in the values obtained for pH among treatments as indicated in Table 1.

Nitrate values for the treatments were between 26.9±9.35 mg/L and 42.5±12.21mg/L. The highest nitrate value (425±12.21mg/L) was observed in FC2 whereas; the lowest nitrate value (26.9±9.35 mg/L) was obtained in both AQ1 and AQ2. However, there were no statistically significant differences in nitrate levels between the treatments (P>0.05) similarly, the Ammonia level recorded ranged between 1.7±0.80 mg/L and 4.6±0.60mg/L.

The experimental setup was observed for twelve weeks starting from March and continued up to May 2018. The work was terminated on 30 May 2018. The initial mean length of the fish culture was 6.1±0.92 cm which increased to 8.4±1.18 cm as shown in Fig. 2 and the mean weight was 4.5±2.30g increased to 8.6±18.60g as shown in Table 2 while the initial mean length of the aquaponics system was 6.0±0.92 cm which increased to 8.7± 1.18 cm as shown in Table 2 and the mean weight was 4.5±2.30 g that increased to 9.23±0.60g as shown in Fig. 3 at the termination of the experiments respectively. There was a significant difference (p<0.05) in the mean length and weight gain of fish among the different sampling dates.

The mean length gain varied from 6.0±0.92cm to 8.80±0.82cm/fish. Fish Culture 2 (FC2) gave the highest mean length gain (8.80±0.82cm/fish) while the two aquaponics systems (AQ1 and AQ2) exhibited the least (6.0±0.92cm/fish). There was no significant difference among treatments

**Table 2: Weekly length of *Oreochromis niloticus* under different culture systems**

| | **LENGTH (cm)** | | | |
|---|---|---|---|---|
| **WKS** | **FC1** | **FC2** | **AQ1** | **AQ2** |
| **1** | 6.1± 0.92 | 6.1±0.92 | 6±0.91 | 6±0.92 |
| **2** | 6.2±0.65 | 6.3±1.11 | 6.3±0.96 | 6.3±0.67 |
| **3** | 6.5±0.57 | 6.9±0.77 | 6.6±0.76 | 6.6±0.76 |
| **4** | 7.1±0.65 | 7.2±1.13 | 7.0±0.95 | 7.2±1.01 |
| **5** | 7.2±0.91 | 7.3±0.98 | 7.2±1.04 | 7.3±1.03 |
| **6** | 7.2±1.57 | 7.5±1.21 | 7.4±1.02 | 7.3±1.43 |
| **7** | 7.4±1.10 | 7.6±1.09 | 7.7±1.10 | 8.1±1.09 |
| **8** | 7.4±1.03 | 7.8±1.14 | 7.8±0.89 | 8.3±0.98 |
| **9** | 7.9±1.23 | 8.1±1.24 | 7.9±0.98 | 8.4±1.06 |
| **10** | 7.9±1.07 | 8.3±1.08 | 8.0±1.09 | 8.5±1.11 |
| **11** | 8.2±1.10 | 8.4±1.10 | 8.3±1.11 | 8.5±1.14 |
| **12** | 8.4±1.18 | 8.8±1.14 | 8.7±1.11 | 8.7±1.18 |

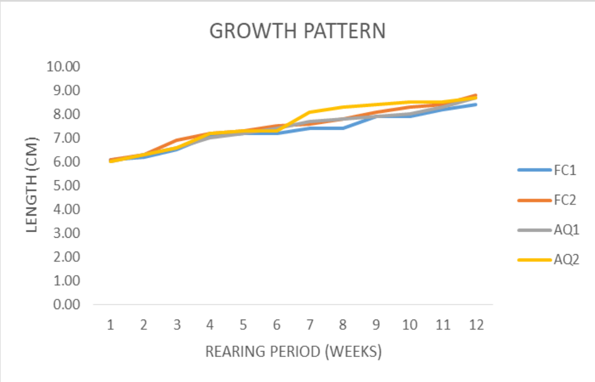


**Fig. 2: Weekly length of *Oreochromis niloticus* under different culture system**

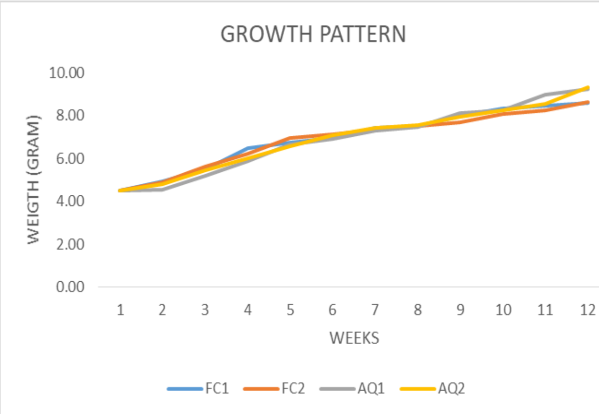


**Fig 3: Weekly growth weight of Oreochromis niloticus under different culture systems**

Length-weight statistics of fish obtained for the experiment given along with the estimated length-weight relationship and coefficient of determination ($r^2$) values was 0.95 in a recirculating aquaponic system. Conversely, the correlation coefficient (r) was 0.97 in the recirculating aquaponics system for tilapia. The correlation coefficient in the experiment indicated that the length and weight of fish were strongly correlated and it was close to 1 (Fig 4, Fig 5), and its positive appearance reflected the positive slope.

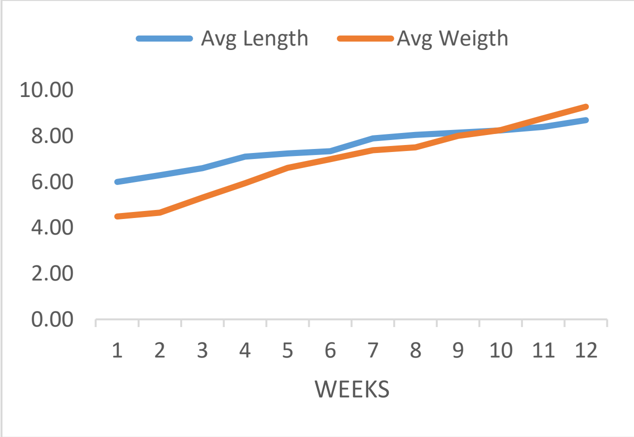


**Fig. 4: length and weight increment of the fish in aquaponics system**

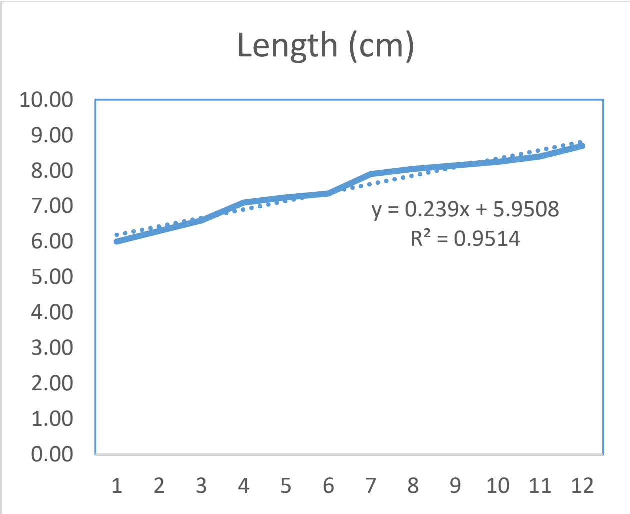


**Fig. 5 regression analysis of length and weight showed a linear relationship for tilapia in recirculating aquaponics system**

**Height, number of leaves, and tomato production**

The highest mean height of the plant was 33.81±5.96 cm found in HP2 on the 30th of May 2018. On the other hand, the plant heights were 22.23±1.46, 27.15±3.51 cm, and 21.16±1.86 in HP1, AP1, and AP2 respectively. There were significant differences in mean heights of plants among the treatments throughout the experiment. (Table 3 and Fig. 6). Moreover, the highest mean number of leaves was 32.67±18.56 in HP2 at the end of the experiment. At the same time, the mean leaf numbers were 20.5±3.71, 8.87, and 8.07±7.60, respectively in HP1, AP1, and AP2.

**Table 3: Plant heights observed during the study period**

| PLANT | HP1 | HP2 | AQ1 | AQ2 |
|---|---|---|---|---|
| WEEK1 | 16.00±0.54 | 13.80±0.66 | 13.50±0.55 | 12.10±0.62 |
| WEEK2 | 17.18±0.56 | 15.73±0.58 | 14.42±0.60 | 13.00±0.57 |
| WEEK3 | 18.25±0.55 | 16.94±0.60 | 15.23±0.59 | 13.81±0.57 |
| WEEK4 | 18.73±0.57 | 17.77±0.56 | 14.98±0.57 | 16.31±0.55 |
| WEEK5 | 20.00±0.66 | 19.07±0.66 | 17.93±0.57 | 18.09±0.65 |
| WEEK6 | 20.66±0.95 | 22.69±0.95 | 22.19±1.12 | 20.31±0.91 |
| WEEK7 | 21.53±0.99 | 27.34±1.75 | 28.62±1.90 | 22.79±1.10 |
| WEEK8 | 20.56±0.96 | 32.76±2.56 | 34.13±2.25 | 25.13±1.57 |
| WEEK9 | 24.50±1.45 | 46.15±2.55 | 36.74±2.50 | 26.24±1.67 |
| WEEK10 | 26.00±1.66 | 58.60±3.44 | 40.03±2.71 | 27.41±1.76 |
| WEEK11 | 31.50±2.50 | 64.67±3.47 | 42.76±2.78 | 28.79±1.91 |
| WEEK12 | 30.67±2.32 | 70.17±3.76 | 45.23±2.56 | 29.98±2.07 |

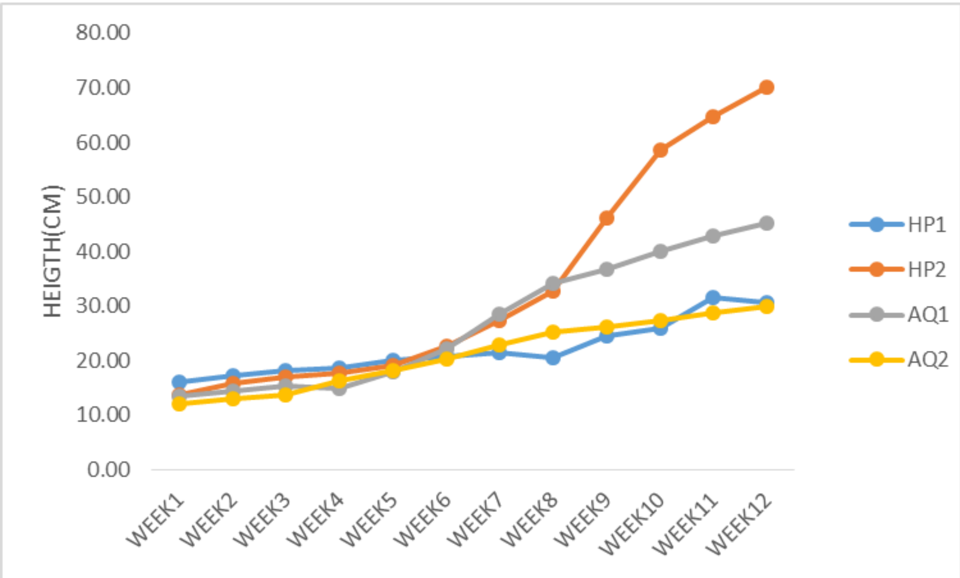


**Fig. 6: Plant heights observed during the study period**

## Discussion

### Water Quality Parameter

The mean water temperature, pH, dissolved oxygen, ammonia, and nitrate levels in this study were found not to be affected by treatments during the twelve weeks of the experiment. Tilapia *(oreochromis niloticus)* is said to be able to thrive in a pH range of 4 to 11, however, they develop quicker in neutral or slightly alkaline water (Shelton and Popma, 2006; Salem *et al.,* 2015). In the present study, the range of pH was 7.4 to 7.8 which is suitable for tilapia growth. In an aquaponics system, Nitrosomonas and Nitrobacter need a pH within 7.2 to 8.2, whereas nitrification is inhibited below the pH value of 5 (Villaverde *et al.*, 1997). Therefore, the pH range in the present study was within the suitable range for nitrification.

Adequate aeration is essential in the aquaponics system for the proper growth and survival of the fish. The DO concentration in the present study was found to vary from 4.07 to 5.69ppm which was within the suitable range of tilapia culture. The fish requires 5 ppm DO for optimal growth, and if the concentration falls below 2.5 ppm significant growth retardation occurred (Popma and Masser, 1999). In the present study, the DO concentration was found to be lower after two weeks from the commencement of the experiment. This might be due to the microbial community and roots respiration. The nitrifying bacteria growing on the root systems could have contributed to oxygen uptake (Okon and Labandera-Gonzalez 1994; Okon and Itzigsohn 1995) Tilapia has a high tolerance to temperature, with optimal growth at 25-30°C. Temperatures of 7 to 35°C are optimal for nitrifying bacteria, with a maximum of 25°C (Wortman and Wheaton, 1991). During the experimental period, the average water temperature was 28.3±0.33°C (21.1°C to 32.6°C) which has been reported as the optimum range for tilapia growth and yield (Meske, 1985).

**Growth Parameters (Weight gain)**

The initial mean length of the fish culture was 6.1±0.92 cm which increased to 8.4±1.18 cm and the mean weight was 4.5±2.30g increased to 8.6±18.60g) while the initial mean length of the aquaponics system was 6.0±0.92 cm which increased to 8.7± 1.18 cm and the mean weight was 4.5±2.30 g that increased to 9.23±0.60g. This is evident from the data that the growth performance of the fish was a bit affected by the culture based on the aquaponic system. Fish growth performance is critical in an aquaculture system, and any supplementary food crop that grows well in an integrated system generates additional revenue and contributes to the economic feasibility of producing high-value aquatic foods. (Lennard and Leonard, 2006). Thus, in these studies, the survival rate of fish was 100% and showed no diminution of growth in the fish.

**Tomato (*Solanum lycopersicum*) Growth**

The growth rate of tomatoes in the experiment was within the range of values reported by (Rana *et al.*, 2011). According to these authors, in a closed recirculating aquaculture system, the plant grows faster. However, (schmautz *et al*., 2016), in their experiment, there was no significant difference in the tomato grown under the different conditions. Nonetheless, the findings revealed that the tomato plant will thrive in an aquaponic system, with nutrients from fish tanks acting as fertilizers. The results were better from the hydroponics system compared to the aquaponics system, this is likely to be as a result of applications of fertilizers and boosters, as reported by Roosta and Hamidpour (2013) that foliar treatment of specific components can successfully ameliorate nutrient shortages in the leaves of tomatoes grown in aquaponics. The plants in the aquaponics system had a low survival rate (57%) compared to the plants in the combined plant in the hydroponics system, with 95% survival and an increase to the tune of 96.3% in terms of plant height, early flowering, and fruiting. In hydroponics systems, most of the tomato leaves wilted and only a few newly shoot observed in the system did well and produce fruits.

**Conclusion and recommendation**

The aquaponic system did not adversely affect the growth of Tilapia. The growth of the tomato plant varies based on the nutritional variability in hydroponics and aquaponics systems. The dynamics of the nutrients in the culture medium were modulated by the nitrification process and general conditions inside the system. Water quality parameters varied due to differences in nutrient conversion and rate of their uptake by the plants. The outcome of this research is useful for farmers who can implement the system in fish farms, tanks, or ponds for creating business opportunities while widening the market for organic plants (vegetables). Based on the available results generated through this study, it could be inferred that the aquaponic system is better than the hydroponics system considering the growth performance of tomatoes and tilapia under these culture systems. A great deal of research will be required to generate more information on the profitability of tilapia in the aquaponic system.

**References**

Akinwole, A. O. and Faturoti, E. O. (2006). Biological Performance of Africa Catfish *(Clarias garienpinus*) Cultured in Recirculation system in Ibadan. *Aquacultural Engineering*, 36: 18-23

Alyssa J., Goddek S., Kotzen B. and Wuertz (2019). Aquaponics: Closing the Cycle on Limited Water, Land, and Nutrient Resources. *Aquaponics Food Production Systems* pp 19-34

Boyd C. E. and Tucker C.S., (1998). Pond Aquaculture Water Quality Management, Kluwer Academic Publishers, Boston, M A (1998) 700 p.

Boyd, C. E. (1990). Water quality in ponds for aquaculture. Alabama Agricultural Experimental. Station, Auburn University, Alabama. 120 pp.

Delgado C. L. (2003). Rising consumption of meat and milk in developing countries has created a new food revolution. *The journal of Nutrition*, 133: 3907S–3910S.

Diver, S. (2006). Aquaponics—Integration of Hydroponics with Aquaculture. ATTRA—National Sustainable Agriculture Information Service (National Center for Appropriate Technology).

Oluwarore, K., (2018, April). Nigeria: Importing fish amidst abundant ocean resources, the paradox of a nation. International centre for investigative reporting, Nigeria. *Earth Journalism Network*. Retrieved from https://earthjournalism.net/

ECETOC (1988) *Nitrate and drinking water*. Brussels, European Centre for Ecotoxicology and Toxicology of Chemicals (Technical Report No. 27).

Falaye, A. E. (1995). Fish Production from Riverine Lake and Forest Swamp of Nigeria. *Nigerian Journal of Forestry*, *24*(1 and 2): 48-50

FAO (2016). The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all. Food and Agriculture Organization of the United Nations, Rome, 200p

FAO (2015). Fisheries and aquaculture in the context of the blue economy

FAO (2013a). Fisheries Global Information System database (accessed15.4.13) http://www.fao.org/fishery/statistics/en.Google Scholar

FAO (2012). The State of World Fisheries and Aquaculture 2012. FAO Fisheries and Aquaculture Department Food and Agriculture Organization of the United Nations, Rome (2012) Google Scholar

Goddek, S. and Keesman, K. J. (2018). The necessity of desalination technology for designing and sizing multi-loop aquaponics systems. *Desalination*, 428:76–85

Ikoyo-Eweto, G.O. (2020) Adoption Prospects and Challenges of Rice-Cum-Fish Farming Technology in the Low-Land Plains of Southern Nigeria (Extension of Sustainability) International *Journal of Agricultural Sciences, Research and Technology in Extension and Education Systems, 10*(2): 61-69.

Lennard, W.A. and B.V. Leonard, (2006). A comparison of three different hydroponic sub-systems (gravel bed, floating, and nutrient film technique) in an aquaponic test system. *Aquaculture International*, 14: 539-550.

Malcolm, J. (2007). The Start of an Obsession. Backyard Aquaponics. *The No.1 Aquaponics Magazine for the Backyard Enthusiast, 1:* 4-17

Meske C. (1985). Fish Aquaculture. Pergamon Press, Oxford, pg. 55.

National Bureau of Statistics; Demographic Statistics Bulletin (2017) (2018)

Okon, Y., and Itzigsohn, R. (1995). The development of *Azospirillum* as a commercial inoculant for improving crop yields. *Biotechnology Advances* 13(3):415–424

Okon Y. and Labandera-Gonzalez C. A. (1994). Agronomic applications of *Azospirillum*: an evaluation of 20 years worldwide field inoculation. *Soil Biology and Biochemistry, 26*(12):1591–1601

Pechsiri, J. and Yakipitiyage, A. A. (2005). Comparative study of growth and feed utilization efficiency of sex-reversed diploid and triploid Nile *tilapia*, *Oreochromis niloticus*. *Aquaculture Research*, *36*(1):45 – 51

Popkin, B. M., Adair, L. S., and Ng, S.W. (2012). Global Nutrition and the pandemic of obesity in developing countries. *Nutrition. Reviews, 70*:3–21

Popma, T. and Masser, M. (1999). Tilapia life history and biology. Southern Regional Aquaculture Center. Publication No. 283: 310-318.

Rana, S., S.K. Bag, D. Golder, S. Mukherjee (Roy), Pradhan, C and Jana, B.B (2011). Reclamation of municipal domestic wastewater by aquaponics of tomato plants *Journal of Ecological Engineering, 37*: 981-988.A

Roosta, R. H and Hamidpour, M. (2013) Mineral Nutrient Content of Tomato Plants in Aquaponic and Hydroponic Systems: Effect of Foliar Application of Some Macro- And Micro-Nutrients, *Journal of Plant Nutrition*, *36*:13, 2070-2083.

Salam, M., Jahan, N., Hashem, S.., and Rana, K. (2015). Feasibility of tomato production in aquaponics system using different substrates. *Bangladish online journal Progressive Agriculture, 25*: 54-62.

Schmautz, Z., Loeu, F., Liebisch, F., Graber, A., Mathis, A., Bulc, T. G., and Junge, R. (2016). Tomato productivity and quality in aquaponics: comparison of three hydroponic methods. *Water, 8*:1–22.

Shelton, W. and Popma, T. (2006). Biology. In Lim, C., and Webster, C. (Eds). Tilapia Biology, Culture, and Nutrition. The Haworth Press, Inc., Binghamton, New York, pp. 4

Thilsted S. H. (2013). Fish diversity and fish consumption in Bangladesh J. Fanzo, D. Hunter, T. Borelli, F. Mattei (Eds.), Diversifying Food and Diets: Using Agricultural Biodiversity to Improve Nutrition and Health, Earthscan, London.

Villaverde S, Garcia-Encina PA, Fdz-Polanco F, (1997). Influence of pH over nitrifying biofilm activity in submerged biofilters. *Water Resource*, *31*:1180-1186.

Viveen W.J.A.R; Ritcher, J. J. C., Oordtrot, P. G. W. I, Jansen, J. A. L, and Huisman, E. A. (1986). A practical manual for the culture of the African catfish, *Clarias gariepinus.*

World Bank (2006). Directorate-General for World Bank Aquaculture: Changing the Face of the Waters: Meeting the Promise and Challenge of Sustainable Aquaculture World Bank, Washington, DC.

Wortman, B. and Wheaton, F. (1991). Temperature effects on biodrum nitrification. *Aquacultural Engineering*, 10: 183-205

https://www.premiumtimesng.com/news/140123-central-bank-worried-that-nigeria-spends-n11-7bn-annually-on-tomato-importation.html

https://www.premiumtimesng.com/news/top-news/109235-nigeria-spends-n11bn-annually-on-importation-of-tomato-paste-agency-boss.html