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Adel Ibrahim Hussain Al Bloushi

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United Arab Emirates University

United Arab Emirates University

College of Science

Department of Biology

EFFECT OF STOCKING DENSITY USING TILAPIA *OREOCHROMIS NILOTICUS* ON AQUAPONIC SYSTEM AND CULTIVATION OF CHERRY TOMATO *SOLANUM LYCOPERSICUM* UNDER UAE CONDITION

Adel Ibrahim Hussain Abdalla Al Bloushi

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Environmental Sciences

Under the Supervision of Dr. Khaled A. El-Tarabily

November 2018

Declaration of Original Work

I, Adel Ibrahim Hussain Abdalla Al Balooshi, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Effect of Stocking Density using Tilapia Oreochromis Niloticuson Aquaponic System and Cultivation of Cherry Tomato Solanum Lycopersicumunder UAE Condition*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Dr. Khaled A. El-Tarabily, in the College of Science at the UAEU. This work has not previously been presented or published or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation, or publication of this thesis.

Student's Signature: ______________ Date: 22/12/2018

Approval of the Master Thesis

This Master Thesis is approved by the following Examining Committee Members:

1) Advisor (Committee Chair): Dr. Khaled El Tarabily

Title: Associate Professor

Department of Biology

College of Science, UAEU.

Signature Khaled El Tarabily Date 19-11-2018

2) Member: Dr. Shyam Kurup

Title: Associate Professor

Department of Aridland Agriculture

College of Food and Agriculture, UAEU.

Signature Date 19-11-2018

3) Member: Prof. Dr. Fatma El-Nemaki

Title: Professor

Department of Department of Fish Ecology and Biology.

Ministry of Agriculture, Agriculture Research Center (ARC)., Cairo, Egypt.

Signature Sabir Bin Muzaffar Date 19-11-2018

This Master Thesis is accepted by:

Dean of the College of Science: Professor Ahmed Murad

Signature ______________________ Date 22|12|٢٠١٨

Acting Dean of the College of Graduate Studies: Professor Ali Al-Marzouqi

Signature ______________________ Date 27/12/2018

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Abstract

The present study was conducted to cultivate tomato plants in aquaponics system in the UAE climatic condition. The cherry tomato *Solanum lycopersicum* plants were cultivated with the Tilapia *Oreochromis niloticus* fish effluent water. The tomatoes were cultivated with three different densities of fish, 100 fish/m^3, 120 fish/m^{3}and 140 fish/m^3. Each greenhouse was 120 m^2 plant cultivation areas and 15.5 m^3 of the fish culture area and the total water stocking volume was 58 m^3. Tomato plants were planted with the ratio of 3 plants/m^2. The introduced fish are fed with 35% protein based commercial floating feed at the ratio of 5% of the total body weight of fish. The fish were fed three times daily at 4 hours' interval. The total duration of the experiment period was 8 months. The first three months were for plant growth and flowering. The tomato fruits harvest started from the fourth month onwards. Every month, fish and plant growth parameter, water quality parameters were examined using proper analytical method. Also, the experiment water, tomato fruits, cultivated fish body proximate composition and mineral nutrient contents were analysed. Finally, the results showed the fish production was significantly higher in140 fish/m^3, the tomato fruits yield significantly higher in 120 fish/m^{3}of fish treatment yield. The main aim is way to cultivate and improve the tomato under UAE climatic condition. So, as per the tomato yield basis the suggestion to UAE farmers, that 120 fish/m^3 density of fish with tomato cultivation was suitable for the UAE climatic condition.

Keywords: *Oreochromis niloticus*, aquaponics system, stocking density, *Solanum lycopersicum*.

Title and Abstract (in Arabic)

تأثير نظام الأكوابونيك على كثافات أسماك البلطي النيلي المختلفة واستدامة انتاجية الطماطم تحت ظروف دولة الامارات العربية المتحدة

الملخص

تشكل أزمة ندرة الغذاء في بعض مناطق العالم إلى جانب الحاجة لتوفير موارد غذائية جديدة اهتماماً متزايداً لدى صناع الأغذية في العالم، وتشهد أنظمة الأكوابونيك تطوراً كبيراً كمصدر جديد للصناعة الغذائية، حيث توفر مثل هذه الأنظمة إمكانية إنتاج أسماك وخضروات متعددة في حيز مكاني واحد؛ لذا تهدف هذه الأطروحة البحثية التعرف على أنسب كثافة سمكية في المتر المكعب الواحد، هذه لحصول على أعلى معدل انتاج للطماطم باستخدام سمك البلطي *النيلي Oreochromis niloticus*، و ذلك في نظام الأكوابونيك المستخدم لإنتاج سمك البلطي و الطماطم في آن واحد، إلى جانب التعرف على تأثير هذين العاملين المهمين على جودة منتجات هذا النظام، علماً أنهما يؤثران على المحتوى الغذائي للمياه التي تعيش فيها الأسماك، وقد تم إجراء التجربة على ثلاث كثافات أسماك في المتر المكعب مختلفة وهي: (100، 120، 140) سمكة لكل متر مكعب، كما تم إجراء تحاليل دورية لاختبار جودة المياه في الأحواض. كما أظهرت النتائج في الكثافة السميكة 140 سمكة/م3 كان اعلى في انتاج الاسماك و في الكثافة 120 سمكة/م3 أظهرت النتائج انتاج أعلى في الطماطم. لذا، وحسب قاعدة محصول الطماطم، فإن اقتراح المزارعين في دولة الإمارات العربية المتحدة، هو أن 120 سمكة / م 3 كثافة الأسماك مع زراعة الطماطم كانت مناسبة للظروف المناخية لدولة الإمارات العربية المتحدة.

مفاهيم البحث الرئيسية: نظام الأكوابونيك، تربية الأسماك، كثافة الأسماك، اسماك البلطي، الطماطم.

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At last, I would like to thank my wife and family for their patience and continuous encouragement throughout my Master program.

Dedication

To my mother for her support and continuous prayers, to all my beloved family,
For being a source of knowledge and inspiration

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List of Abbreviations

AED	United Arab Emirates dirham
DO	Dissolved oxygen
DWC	Deep-water culture
NFT	Nutrient film technique
RAS	Recirculating aquaculture systems
TAN	Total ammonia nitrogen
TDS	Total dissolved solids
UAE	United Arab Emirates
UVI	University of the Virgin Islands

Chapter 1: Introduction

1.1 Principles of aquaponics

Population is gradually increasing and there is a necessity to find out new techniques to reduce the gap between population needs and agricultural production. One of the new techniques called “aquaponics” in which we can utilize the output so fish farming in growing vegetables, i.e., lettuce, cucumber, tomato, cabbage and so on. In this technique a minimum requirement of nutrients could be used, furthermore removal the fish feces (Khater, 2006). Aquaponics is the integration of aquaculture (fish farming) and hydroponics (growing plants without soil). In aquaponic system the fish consume food and excrete waste primarily in the form of ammonia. Bacteria convert the ammonia to nitrite and then to nitrate **(**Diver, 2000; Khater et al., 2015; Rakocy, 2002; Selock, 2003; Lee, 2004; Okimoto, 2004; Karen, 2005; Nelson, 2006a, b, c; Graber and Junge, 2009).

Aquaponics use available fish water rich in fish waste as nutrients for plant growth. Another advantage of this mix is the fact that the increase in nutrients does not need to be eliminated through the periodic exchange of freshwater fish as practiced in aquaculture systems. This system produces a symbiosis between fish, microorganisms and plants and encourages the sustainable use of water and nutrients, including recycling. Within this synergistic interaction, the relevant ecological weaknesses of aquaculture and aquaculture are transformed into strengths. This combination substantially minimizes the need for input of nutrients and output of waste, unlike when running as separate systems (Goddek *et al.*, 2015).

1.2 Aquaponics for aridland

Agriculture is the prime target for water conservation efforts, as it plays an important socio-cultural role (heritage) and within food security considerations. So, improving water management, performances and productivity in major agricultural systems is major issue within the strategy of most Gulf countries. Crop production in the UAE faces many land, water and management challenges. Vegetable production under greenhouse conditions provides an alternative to growing crops under open conditions. However, the production of greenhouse vegetables presents its own challenges that arise from agriculture in arid land conditions in the UAE. These challenges include the need for appropriate management and control of limited water resources within the typical land, capital and labor scenarios, as well as environmental constraints. The main environmental constraints that UAE farmers must face are agricultural water problems, limited water scarcity and high salinity levels in available water (Al-Qaydi, 2007). In 2012, the total value of locally produced vegetables in the UAE was estimated at AED 364 million (AED) by the Ministry of Water and Environment, 2014 (Ministry of Water and Environment, 2014) or approximately $100 million USD (using an exchange rate of 1USD=3.65AED). A large majority of the vegetable farming takes place in the Abu Dhabi Emirate. UAE Bureau of Statistics (2013) data showed that about 1547 out of 3941 hectares (or~40%) of the total vegetable are a cultivated in the country is located in Abu Dhabi. Abu Dhabi Food Control Authority (ADFCA) statistics showed that 4370 out of 10,003 (or 44%) of the greenhouses in Abu Dhabi Emirate were designated as non-active as of 2010 –2011 by ADFCA, 2014 (ADFCA, 2017).

In the United Arab Emirates, the number of greenhouses during the period 2005-2011 increased by 48% and 14,777 had been installed by 2011. This was accompanied by an increase of 78% in the area so that the greenhouses covered 493 hectares in 2011. There were some regional and with There are differences between Abu Dhabi in recording an increase in numbers while all other regions show a decrease. Total crop production reached 2.1 million tons in 2010 and 74% of it was from fodder and field crops. Fruit trees contributed 19%, while vegetables accounted for just 7%. The situation of protected agriculture changed significantly in 2011 when total production fell to 1.2 million tons and this may be due to salinity and water scarcity problems which call for better use of saline water and freshwater saving **(**NBS, 2013). The UAE is very dependent on foreign markets for its needs in fruit and vegetable, it imports 62 and 47% of vegetables and fruit needs respectively which indicates that there is a great potential to increase the horticultural production in the UAE as well as the GCC region (Woertz *et al.*, 2008).

Middle East countries are the most water-scarce countries in the world, such as Saudi Arabia and Jordan, have per capita annual water resources less than 200 m^3. Overall, it is also expected that by 2025, due to population increase, the regional average water availability is projected to be just over 500 m^3 per person per year (Abdel-Dayem and McDonnell, 2012). The GCC (Gulf Cooperation Council) countries are considered one of the most water-scarce regions in the world and facing over the coming years the most severe intensification of water scarcity in history. Agriculture is the sector using by far the majority of available freshwater resources (>85%) of which 92% is used for dates and forage production (Wittwer and Castilla, 1995; Kotilaine, 2010).

In arid and semi-arid regions, the rational use of water in agriculture is of fundamental importance for obtaining good profits and reducing water use conflicts. Integrating agriculture in fish culture can be a way of reducing these conflicts, with the following advantages: improve fish pond water quality (Ghate and Burtle, 1993), reduce the environmental impact of discharge nutrient-rich water into receiving streams (Billard and Servrin-Reyssac, 1992) and reduce the cost of water and the amount of chemical fertilizer needed for crops (Brune, 1994; Azevedo, 1998). Integration results in more diversified farm products increase cash incomes, improve quality and quantity of farm products, improve environmental soundness and increase efficiency through the exploitation of unutilized resources. The long-term performance of diversified farms is better than non-diversified enterprises, because they are able to deal with market and climate changes (Dhawan and Sehdev, 1994; Kokic *et al*., 1995). They are also less risky especially for resource-poor farmers in developing countries (Lightfoot *et al*., 1993). Alderman, (2015) reported that the Middle East as well as North Africa are particularly well suited for aquaponic agriculture. The use of aquaponic agriculture in these regions could be greatly beneficial to public good, environmental quality, and economic stability.

1.3 Aquaponics plant cultivation

The Aquaponic system is one of the economical solutions to get the plants and fish of waste water from the fish farm because it provides nutrients and produce fresh vegetables. With the use of this system in succession will decrease its cost and become more economical. The produced plants via this system considered as an organic product which is safer for human consumption (Khater and Ali, 2015**)**. Integrating fish culture with plants has been tested in hydroponic systems, where effluent was used as a nutritive solution. These systems were designed for lettuce (Parker *et al.*, 1990; Seawright, 1993), tomatoes (McMurtry *et al.*, 1993) and other crops (Racocy *et al.*, 1993). Some experiments were also designed for greenhouses (Azevedo *et al.*, 2002; Pereira, 2002). For field crops, however, few studies of integrating aquaculture and agriculture have been conducted (Al-Jaloud *et al.*, 1993; Olsen *et al.*, 1993; D'Silva and Maughan, 1994; Khan, 1996; Palada *et al.*,1999). Plants that commonly used in aquaponics are water spinach (Endut *et al.*, 2010, 2011; Effendi *et al.*, 2015a), spinach (Shete *et al.*, 2013), Lettuce (Simeonidou *et al.*, 2012; Buzby and Lin 2014; Effendi *et al.*, 2015b; Wahyuningsih *et al.*, 2015), tomato (Roosta and Hamidpour, 2011), cucumber (Tyson *et al.*, 2008; Graber and Junge 2009), and pepper (Roosta and Mohsenian, 2012). Vegetable such as lettuce can be used in the aquaponics system, because it can be harvested in a short time and relatively fewer problems with pests compared with fruiting plants, have low to medium nutritional requirements and is well adapted to the Aquaponics systems (Diver, 2006; Rakocy *et al.*, 2006; Dunn, 2012).

Nile Tilapia (*Oreochromis niloticus*) is a type of fish used in the Aquaponics system (Liang and Chen, 2013; Delis *et al.*, 2015; Wang *et al.*, 2016). Nile Tilapia has a good tolerance level to various environmental conditions, well-grown in an Aquaponic system using vegetables (Effendi *et al.*, 2015c), and has a high economic value (Diver, 2006). Tilapia is the basic requirements for a successful biological process in the Aquaponics system (Love *et al.*, 2014). Tilapia has a great attention because of its high availability, easily cultivable nature, fast growing, stress and disease-resistant and highly adaptable to a wide range of environmental conditions such as pH, water temperature, dissolved oxygen (DO), salinity, light intensity and photoperiods (Hussain, 2004; El-Saidy and Hussein, 2015). Due to these characteristics, Tilapia culture is being practiced in most of the tropical, subtropical and temperate regions in order to reduce the global rising demands for protein sources (Ng and Romano, 2013). In a study conducted by Palm *et al*. (2014), *Oreochromis niloticus* is used for better growth of lettuce (*Lactuca sativa*) and cucumber fruit (*Cucumis sativus*) in the aquaponics system. Further, another study conducted by Knausand Palm (2017) recorded better growth in basil (*Ocimum basilicum*) and parsley (*Petroselinum crispum*) when used *O. niloticus* in the aquaponics system. Consequently, under an identical aquaponics system design, optimal fish and plant choice govern the growth performance of the cultivated plants (Knaus and Palm, 2017).

Britto*et al.* (2002) stated that nitrate is taken up by the plant at better rates than ammonia which can be toxic to plants. Ammonia concentrations at elevated levels can inhibit nutrient uptake in plants by altering the ionic capacity of the water medium. Depending on the plant species sensitivity, symptoms of ammonia toxicity appear with external ammonia concentrations above 0.1 - 0.5 Smol/L. Timmons *et al*. (2002) stated that re-circulating aquaculture is an environmentally responsible alternative to fishing and virtually eliminates bycatch waste which occurs in wild fisheries. Water discharge/replacement requirements was 5% to 10 % of re-circulating water volume per day makes these systems subject to discharge restrictions due to concerns with environmental waste management. RAS can produce more fish per liter of water than other types of aquaculture systems therefore reducing water used.

Watanabe *et al*. (2002) stated that tilapia can withstand low dissolved oxygen levels, but optimal growth occurs with levels greater than 2 mg/l. Al-Hafedh *et al*.

(2004) stated that fish waste and accumulated feed builds up in the system. Nitrogen, phosphorous, and organic matter accumulate in high quantities in aquaculture systems. Nitrogenous wastes are produced when nitrogen in the form of ammonia is excreted by the fish. Ammonia is the by-product of protein synthesis by the fish. Nutrient levels from fish aquaculture are suitable for plant growth and can be manipulated by increasing fish biomass and feed rate or by increasing the protein levels in the feed.

Rakocy *et al*. (2004) stated that Aquaponics is the most efficient food production system in terms of the amount of product produced per volume of water. It takes approximately 500 liters of water to produce $100 of product (fish and lettuce), whereas producing cattle takes more than 100 times as much water to produce a $100 of product.

Ghaly *et al*. (2005) stated that high-value vegetable crops, such as tomato, lettuce, cucumber and sweet basil, had cultured in hydroponic media. It was more desirable to grow higher priced products such as herbs to get the best profit per unit area of Aquaponics bed. Lin (2005) stated that since the concept of Aquaponics implied the use of fish waste as a major source of nutrient for the plant production, the nutrient balance in the fish feed is crucial for the plant. The requirements for potassium were different for plants and for fish. Fish meal, the major component of the fish feeding formulations is not always rich in potassium. The measured level of potassium in the fish effluent was 10-fold less than that of calcium and 5-fold less than sodium in the beginning of the experiment. The recommended Ca: K (calcium: potassium) ratio for hydroponic production of most crops was between 2:1 and 1:1. Ca (calcium) and Na (sodium) interfere with K (potassium) uptake. The increased level of these elements can cause severe K starvation. Thus, the preliminary observations in this Aquaponics system revealed an intrinsic nutrient imbalance in the system based on fish feeding feeds prepared with plant nutrients.

Wilson and Brian (2006) studied on comparison of three different hydroponics sub-systems (gravel bed, floating and nutrient film technique) in an Aquaponics test system. Murray cod, *Maccullo chellapeelii* (Mitchell), and green oak lettuce, (*Lactuca sativa*), were used to test the differences between three hydroponic subsystems, Gravel Bed, Floating Raft and NFT, in a freshwater Aquaponics test system, where plant nutrients were supplied from fish wastes while plants stripped nutrients from the waste water before it was returned to the fish. The Murray cod had FCR's and biomass gains that were statistically identical in all systems. Lettuce yields were good, and in terms of biomass gains and yields. Overall, in brief, the results suggested suggest that NFT hydroponic sub-systems are less efficient at both removing nutrients from fish culture water and producing plant biomass or yield than Gravel bed or Floating hydroponic sub-systems in an Aquaponics context.

Tyson *et al*. (2007) stated that nitrifying bacteria is inhibited below a pH of 6.5, with an optimum pH of 7.8 depending on bacterial species and temperature. Andreas and Junge (2009) conducted an experiment where tomato and cucumber cultures were established in the LECA filter and nutrient removal rates calculated for42-105 days. The highest nutrient removal rates by fruit harvest were achieved during tomato culture: over a period of greater than 3 months, fruit production removed 0.52, 0.11 and 0.8 gm-2d-l for N, P and K in hydroponic and 0.43, 0.07 and 0.4 gm-2d-l for N, P and K in aquaponics system. In the Aquaponics system, 69% of nitrogen removal by the overall system could thus be converted into edible fruits.

Graber *et al*. (2008) ascertained that there are several benefits to the owner of a backyard Aquaponics system. Firstly, the waste produced by the fish is recovered by the plant instead of being expelled to the environment. Water exchange is minimized since the growing medium and plants act as bio-filters, cleaning and returning the clean water to the fish tank. The surface area of the grow bed provides the area for bacterial growth and is related to the treatment capacity of the system. The treatment capacity has a unit of mass removal per unit time.

Rana *et al*. (2011) studied on searching of low-cost eco-tech for the reclamation of municipal domestic wastewater, tomato plants (*Lycopersicum esculentum*) were cultivated on the floating bed of pulp-free coconut fiber over four different concentrations of wastewater (25%, 50%, 75% and 100%) and groundwater as control, in 10 L plastic bucket for two months. The study revealed that PO_4-P was removed by 58.14–74.83% with maximum removal at 50% wastewater. More than 75% removal of NO_3-N was observed in all treatments. Both COD and BOD were reclaimed highest at 100% wastewater by 61.38% and 72.03%, respectively. Ammonium-N concentration was subsided below the toxic level in all the treatments. The population of coliform bacteria (*Escherichia coli*) was reduced to 91.10–92.18% with maximum efficiency at 100% wastewater. Growth performance was observed relatively better at 100% wastewater. Crop production as the value addition of this technology was also recorded maximum at 100% wastewater.

1.4 Stocking density of tilapia under intercropping aquaponics

Rahmathullah *et al*. (2010) reported in aquaponics, nutrient-rich effluents are used from fish tanks to fertilize the aquatic production family. This is good for fish because plant roots bacteria remove nutrients from water. These nutrients generated from fish manure, algae and decaying feed are contaminants that can accumulate to toxic levels in fish tanks, but instead act as liquid fertilizer for water plants. In contrast, the aquatic family works as a biological process to dispose of ammonia, nitrate, nitrite and phosphorus, so that fresh water can be recycled into fish tanks. Nitrogenous bacteria that live in pebbles and in association with plant roots play a crucial role in the nutrient cycle. Without these microorganisms, the whole system will stop working. Ashley. (2007), Rahman and Marimuthu. (2010), and Ayyat *et al*. (2011) reported that the storage density of fish in the aquaponics system is very important for the smooth functioning of the system. The fish density of the fish should be optimized to maintain water quality suitable for fish and plant growth. Hence, the present study was conducted to observe the effects of stocking density on the growth and production parameters of tilapia in an aquaponics system and to determine a suitable stocking density. Through optimal stocking density, one can obtain maximum production without any effects on environment, optimal health, economic benefits, and minimum occurrence of physiological and behavioral disorder.

Timmons (1996) reported that the conceptual aspect of Aquaponics is the balancing of nutrients within a given system. The nutrients are delivered to the system through the source of income, in which case feed the fish. The protein content of the feed determines the amount of nitrogen available to the plants after absorbing the fish and processing the nutrients. Fish density, protein content in nutrition, feeding rate prompts the nutrient loading of the system. A balance between the amount of nutrients produced from the fish system and nutrient requirements in plants can improve the use of resources and the productivity of the system. Villaverde *et al.* (1997) stated that for Nitrosamines and Nitrobacteria, the optimum pH is within 7.2 to 8.2, whereas nitrification is inhibited below a pH of 5. Popma *et al.* (1999) stated that Continuous supply of adequate amounts of aeration to fish and the bacteria bio-filter in a re-circulating system is essential to its proper operation. Tilapia needs at least 5 mg/L of dissolved oxygen for optimal growth, and if concentrations fall below 2.5 mg/L they have significant growth retardation. Prinsloo *et al*. (1999) showed that nitrification transforms 93% to 96% of nitrogenous fish wastes into nitrate.

Diver (2006) stated that the fish species is an important consideration when setting up an Aquaponics system. Trout, perch, Arctic char, tilapia and bass are just a few of the warm and cold-water fish suitable for re-circulating aquaculture systems. However, most commercial Aquaponics systems in North America were based on tilapia. Fitzsimmons (2006) stated that tilapia is, a hardy fast-growing fish with a low protein requirement making it a primary target for Aquaponics re-circulating systems. Tilapia fish are omnivorous and have a relatively low protein requirement in comparison to other carnivorous fish. Rakocy *et al*. (2006) stated that in developed countries concerns about pollution issues had raised interest in aquaponics system as a valid option to get rid of aquaculture wastes through the production of high-value vegetables.

Endut *et al*. (2009) recommended that Aquaponics systems are designed to provide an artificial, controlled environment that optimizes the growth of fish and soil-less plant, complete control over water quality, the production schedule and the fish product, while conserving water resources. In his experiment Five different water flow rates (0.8, 1.6, 2.4, 3.2, and 4.0 l/min) were tested in order to relate 5 nutrients removal, water quality and plant growth. It was found that the highest plant growth rate was at 1.6 l/min and that high growth rates and yields were generally seen when the major growth-limiting nutrient nitrogen, was delivered as a combination of ammonium and nitrate. In terms of fish growth rate, there were no significant differences in the feed conversion ratio (amount of food given vs. weight gained) at various at flow rates. The-results showed that the Aquaponics system removed BOD (47-65%), total suspended solids (67-83%), NH3-N (64-78%), N02-N (68-89%), and demonstrated a positive correlation with flow rates. NO3 removal ranged from 42-65%, but decreased proportionately with flow rate after 1.6 l/min. It was suggested that the higher flow rates resulted in less contact time between nitrate and denitrifying bacteria, thus decreasing the system's denitrifying performance. Total phosphorous concentration ranged between 42.8% and 52.8%, and again had highest removal rates at 1.6 l/min. It was concluded that both plant growth and fish production were better with a flow rate of 1.6 l/min.

Normala *et al*. (2010) noted that fish culture could be carried out in aquaponics system over extended periods, mint stocks had to be harvested at shorter intervals, preferably every fortnight and replaced by fresh stocks. Keeping the same plant in the system led to fall in biomass and would impair the water quality since nutrient uptake in unhealthy plants was slower and might even 30 ceases if the culture would continue. In fact, shortage of certain nutrients such as iron, calcium and potassium in soilless culture might occur. While most of the nitrogen and phosphate requirements were met from the fish waste, there could be a deficiency of potassium and some micronutrients, including iron and magnesium. Philippe (2010) conducted a study is to investigate the techno-economic feasibility of operating an aquaponics farm in South Africa. The study found that currently aquaponics in South Africa is hindered by a number of constraints that result in it being a high-risk venture with meagre returns on investment. However, the study showed that if an aquaponics system were designed, built and managed correctly, it could theoretically be an economically viable venture.

Steve and Rinehart (2010) stated that fish raised in re-circulating tank require good water quality. Water quality testing kits from aquaculture supply companies are fundamental. Critical water quality parameters include dissolved oxygen, carbon dioxide, ammonia, nitrate, nitrite, pH, chlorine and other characteristics. The stocking density of fish, the growth rate of fish, feeding rate and volume and related environmental fluctuations can elicit rapid changes in water quality; hence, constant and vigilant water quality monitoring is essential.

Michael (2012) investigated an innovative approach to recapture nutrients from post-consumer food waste by converting it into a pelletized fish food for a bench-scale Aquaponics system. Two treatments, each with three replicated Aquaponics systems, were constructed to determine the effect of using food waste for fish and lettuce production. Food waste pellets had significantly more fat, less mineral content, and similar protein and fiber content compared to commercial fish feed. Nile Tilapia (*Oreochromis niloticus*) had significantly greater specific growth rate (SGR) and food consumption rates on the commercial diet than those on the food waste diet. The feed conversion ratio (FCR) between treatments was similar. Lettuce biomass production was significantly reduced food waste systems. Palatability of post-consumer food waste seemed to be the most significant factor to overcome.

Jason and Austin (2013) conducted an experiment to compare the growth of tomatoes, beans, and pea plants in an aquaculture medium with fish and no fish by monitoring the changes in ammonia, pH, nitrate, phosphate, temperature, and salinity of water overtime. Results showed that there were no significant growth differences by the height of peas, tomatoes, and beans when growing between Aquaponics vs. traditional soil. However, there were significant differences between growing plants in Aquaponics vs. the control hydroponics with water only.

El-Sayed *et al.* (2015) studied the utilization of effluent of fish farms in tomato cultivation and the experiment was carried out to study to which extent the content of nutrient in water farming is sufficient for growing tomato plants, in order to increase the yield and reduce the production costs. The obtained results can be summarized as follows: The nutrient consumption was increased within increasing flow rate. The N, P, K, Ca and Mg consumption significantly increased. When the flow rate increased from 4.0 to 6.0 L/h, simultaneously increase the root and shoot length. As well as the fruit yield, mass of production also significantly increased using the effluent fish farm could save fertilizers which equivalents 0.13 LE kg-1 fruits (130 LE t -1fruits). Besides, it is considered as an organic product which is safe for the human health.

Sreejariya *et al.* (2016) stated that the Aquaponics technology produced vegetables as safe for human consumption as those produced by more traditional farming systems in terms of nitrate content. Indeed, this nutrient concentration in the sap of the lettuce leaves midrib in both experiments were always in accordance with the maximum permissible leaf nitrate concentrations in vegetables for human consumption. Another major finding was that it is possible to get the same performance when reducing the duration of the pumping for water recirculation to 11 to 13 hours, either during daytime or night time. Finally, it allowed to determine that 30% shading was the optimal shading rate for ensuring lettuce leaf quality and consumer safety without affecting its growth. However, shading increased the Nitrate concentration in the plant, although it always remained safe for human consumption.

Johnson *et al*. (2017) compared two harvest methods [Cut-and-Come-Again (CC); and Once-and-Done (OD) for lettuce production in an Aquaponics system and his findings and conclusion showed that the CC method in an FTS had an advantage over the OD method in productivity because it allowed multiple harvests in a shorter cultivation time and had a benefit of increasing yield. Additionally, the production would be further increased by utilizing a combined harvest method of CC and OD, and the cost labor and materials could also be reduced.

1.5 Tomato cultivation

Tomato is one of the most important crops around the world, because tomato is the second most important vegetable in the world after potatoes, with annual production of 161.8 million tons in 2012. Tomato is one of the most important economic vegetable crops, practiced by the Egyptian farmers. The total cultivated area of tomato is about 454,800 Fadden's and total production of tomato in 2012 was 8.6 million tons (FAO, 2012; Dondarini *et al.*, 2014). According to the latest available data, in 2012, tomato area in the world amounted to 4.8 million hectares, denoting, during the last ten years (2012–2003), an increase of 17.3% (FAO, 2014).

In the last few years, in fact, the tomato is being cultivated, increasingly, in new producing countries to the detriment of the traditional growing areas. This occurs, firstly, due to the low costs of human labor and for the continuous investments that, in recent years, have affected, not only cultivation techniques, but also commercial and marketing strategies, improving the tomato supply chain management (Causse *et al*., 2010; Sinesio *et al*., 2010). China (1,000,000 ha) and India (870,000 ha) represented the two main producing countries, covering 38.9% of world tomato area, followed by Turkey (6.3%), Nigeria (5.6%), and Egypt (4.5%). China, in addition to growing area, was the top country for harvesting quantities (50.0 million tons), followed by India (17.5 million tons) and the USA (13.2 million tons); these three countries reached 49.9% of the total world tomato production. Further, Italy with 91,850 ha and 5.1 million tons, in 2012, represented the ninth country for world the tomato area and the seventh for harvesting production. Greenhouse tomato cultivation played an important role, involving 7558 hectares (7.3% of Italian tomato area) with a production of 512,330 tons (8.6% of harvested tomato) (I Stat, 2014).

Castro *et al.* (2006) and Schmautz *et al*. (2016) tested and reported that the fish effluent can be used to irrigate cherry tomato plants, irrigation with fish effluent increased cherry tomato productivity in comparison with irrigation using well water, fish effluent effect was more pronounced when no fertilization was used or when fertilization does not supply all plant needs, the increment in tomato productivity, when plants were irrigated with fish effluent, was due to an increase in fruit number, fish effluent can complement or even substitute for organic fertilizers in cherry tomato production and irrigation of tomato plants with fish effluent, increased the rate of return.

Jchappel *et al*. (2008) and Roosta and Hamidpour (2011), and Salam *et al*. (2014) studied a demonstration of tilapia and tomato culture utilizing an energy efficient integrated system approach and concluded that an aquaponics tomato and tilapia integrative cultivation is financially feasibility and positive effect on production. Reported that themajor advantage of rearing high value crops such as fish and tomatoes using waste water from the fish tank which fertilize the plants continuously.

Roosta and Hamidpour (2011) conducted a study on the mineral nutrient content of tomato plants in Aquaponics and hydroponics systems: effect of foliar application of some macro-and micro-nutrients. The concentrations of Mg, Na, Fe and Zn were higher in the leaves of aquaponics-grown plants as compared to hydroponics. However, the fruits concentrations of the studied elements were significantly lower in plants grown in the Aquaponics as compared to those of the hydroponic. Foliar application of K, Mg, Fe, Mn, Zn and especially Cu increased their corresponding concentrations in the leaves of Aquaponics-treated plants. It was not observed significant effects of foliar spray of the elements on their concentrations in the fruits of Aquaponics-grown plants, whereas, foliar application of K, Fe, Mn, Zn and Cu caused a significant increment of applied element concentrations in the fruits of hydroponic-grown plants. The results suggest that foliar K application is an effective way to increase K concentrations in tomato grown in the Aquaponics systems. The study showed that, nutrient contents of tomato leaves were significantly higher than fruits. Higher Ca content of leaves was observed in hydroponic-treated plants than aquaponics-treated plants, whereas, Ca concentration in fruits was not affected by growing systems. The plants were slightly greener in the Aquaponics compared to hydroponics. A higher ammonium form of N in the Aquaponics solution and high level of Mg, Fe and Zn in the leaves of aquaponics-grown plants could be part of the reason for this green color. These findings indicated that foliar application of some elements can effectively alleviate nutrient deficiencies in the leaves of tomatoes grown on the Aquaponics, although they have no effect on the concentration of the applied element in fruits.

1.6 Objective of the study

1. As per the previous researcher's suggestions, the present study was conducted to determinine the optimal tilapia fish density for cultivating the cherry tomato in an aquaponics system in UAE climatic condition. In this study, the recirculation water quality (physico-chemical) parameters such as pH, temperature, electrical conductivity, total dissolved solids, total ammonia, nitrogen, nitrate, alkalinity, dissolved oxygen level and micro minerals were analysed.
2. Find out the produced fish and tomato proximate composition, nutrient concentration, quality and quantity of production material.
3. Compare and conclude the suitable density of fish for cultivate the cherry tomato in an aquaponics system in UAE climatic condition.

Chapter 2: Materials and Methods

2.1 System description

Aquaponics units inside a 400 m^2 greenhouse with a 120 m^2 plantation area in four turfs (each 24.4*1.23*0.42 m^3 L W H covered with 2-inch-thick perforated Styrofoam sheets), two circulars (3 m diameters and 1.2 m high) fish tanks each with 7.7 m^2. Were used fish tanks which was connected to water treatment units which include cone shape bottom (2 m^2 diameter with water volume of 4.5 m^3), swirl separator for mechanical filtration connected to U-tube to remove sludge by siphoning followed by two connected biological filters for nitrification (1.8*80*0.6 m^3 each) tanks one third filled (35 kg) with plastic media (HDPE polymer with very high surface area; 899 m^2/m^3) from Pentair's Sweetwater USA. Then water from the biological filters move to a CO_2 stripping tank (1*0.6*0.6 m^3) before moving to the four plantation raceways. The Water moves in the system at a rate of a 10 m^3L/hour from fish tanks to the water treatment system and plantation raceways by gravity and returns to fish tanks using a 3 HP water tanks. The Total water volume was 58 m^3. The system was aerated by an air blower (S53-AQ Sweetwater Regenerative Blower 2.5 HP). (MFD BY; Aquatic Eco-Systems INC Apopka, Florida USA) through one-inch PVC pipe and rubber hose. Each fish tank has 20 silicon air stones (each 20 cm length) and each water trough has 10 air stones (each 10 cm in length). The water consumption from evaporation and evapotranspiration and cooling system was measured using two water meters (KENT PSM 15 mm water meter PN 16, GRUNDFOS, England). Electricity consumption was measured using one electric meter (Elster A1100 poly- phase meter by Elster metering Ltd. Stafford). One air cooler fan:Euroemme® EM50n, exhaust fan with

1.5 HP motor (Fan, Propeller diameter 1,270 mm. 6 Kista, blade, Sweden). One water pump was used for cooling pad: GRUNDFOS DK-8850, 1 HP single phase motor capacity of water pulling a 5 m^3/h (Figure 1).

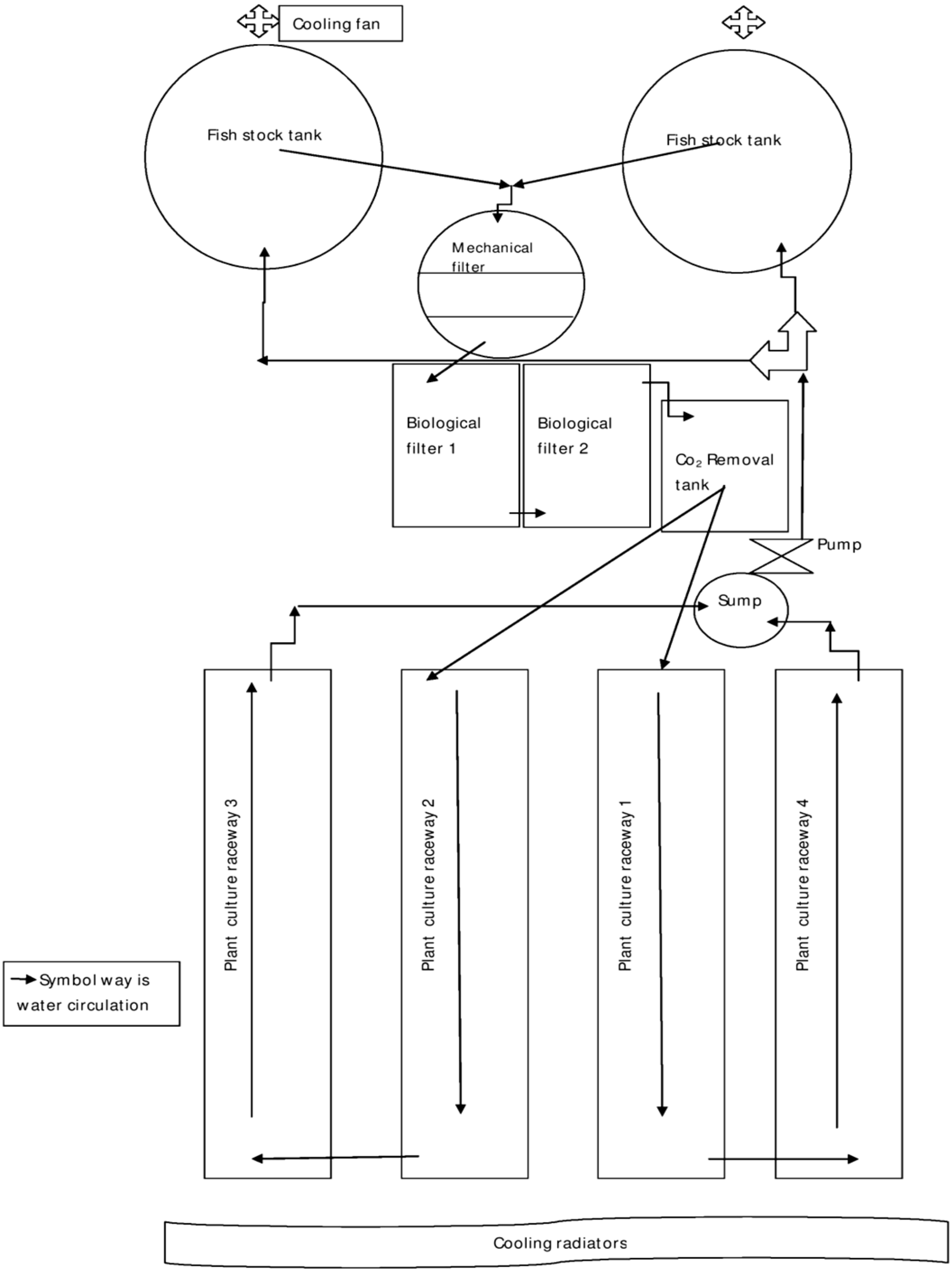

Figure 1: Flow diagram of the experimental aquaponic system aquaculture research station, Falaj Hazza, UAE University

Table 1 shows the total system water volume in an aquaponics unit, and the number of plants in one greenhouse is shown in Table 2.

Table 1: Total system water volume in an aquaponics unit

Tanks	**Water volume**
Fish Stock Tank 1	7.754 m^3
Fish Stock Tank 2	7.754 m^3
Mechanical filter	4.502 m^3
Bacterial Tank 1	0.747 m^3
Bacterial Tank 2	0.747 m^3
Water Supply tank	0.186 m^3
Race way 1	9.004 m^3
Race way 2	9.004 m^3
Race way 3	9.004 m^3
Race way 4	9.004 m^3
Pumping tank	0.209 m^3
Total	**57.95 m^3**

Table 2: Greenhouse number of plants details in an aquaponics unit

No of cultivation raceway	No of stay foam sheet in a raceway	No of plants in a floating raft	Total no of plants in a green house	One race way surface area	Plants growing in per square meter
4	39	2	342	30 m^2 X 4 = 120 m^2	3 plants/ square meter
One floating foam sheet Length – 1.265 m Width – 0.60 m	One sheet is 0.76 m^2				

One race way surface area is = 30 m^2
Four raceway plant cultivation surface area is = 120 m^2
Total no of plants in a greenhouse = 342 Nos
Therefore, per m^2 surface area contain plants no (342/120) = 3 plants per m^2

2.2 Equipment’s in aquaponics system

Water meter: KENT PSM 15 mm water meter PN 16 (Supplied by: Elster Solutions LLC, Dubai, UAE)

Air cooler fan: Euroemme® EM50n, Exhaust fan with 1.5 HP motor. (fan) Propeller diameter 1,270 mm. 6 blade.

Air blower: S53-AQ Sweetwater Regenerative Blower 2.5 HP. (MFD BY; Aquatic Eco Systems, INC).

Electric meter: Elster A1100 polyphaser meter (Mfd by: Elster metering Ltd. Stafford)

Water pump for Fish tank: GRUNDFOS DK-8850**,** 1 HP 3 phase motor Capacity of water pulling - 10.6 m^3/h. (Mfd by, GRUNDFOS, Bjerringbro, Denmark).

Water pump for cooler: GRUNDFOS DK-8850, 1 HP single phase motor Capacity of water pulling – 5 m^3/h. (Mfd by, GRUNDFOS, England).

2.3 Fish introduction and acclimatization in aquaponic tank

Before starting the experiment, the entire aquaponics system was well cleaned and kept at dry for one month. Then, the tap water was filled in the full aquaponics system tanks like fish stocking tank, mechanical filter, biological filter and plant cultivation raceway tanks. The initial water quality parameters were analyzed, and the water circulation was started in a closed condition of aquaponics system for one week without fish. After one week the water was taken for quality analyses and checked with standard aquaponics water quality parameters. If the water quality was not suitable with the standard water chart, the water quality was adjusted to the level of aquaponics water quality standard for getting appreciable growth of fish and tomato yield (The alkalinity level is adjusted with calcium hydroxide). The initial water physic chemical parameters are listed below in Table 3.

Table 3: Initial water quality parameter of the aquaponics system and standard water quality

Parameters	System 1	System 2	System 3	Standard
pH	6.68	6.59	6.75	6 – 8.5
Temperature (°C)	28.9	27.8	28.2	17 - 34
Dissolved Oxygen (mg/l)	5.2	5.1	5.2	4 - 8
Electric conductivity (µS/cm)	-22.5	-29.1	-22.3	1500
Total Dissolved Solids (ppm)	169	175	165	800
Total Ammonia (mg/l)	0.03	0.02	0.03	< 3
Total Nitrate (mg/l)	0.08	0.05	0.07	< 400
Nitrite (mg/l)	0.003	0.005	0.004	< 3
Alkalinity (mg/l)	10	13	13	60 - 140

Standard from: FAO aquaponics manual, 2014.

After that, the selected tilapia (*Oreochromis niloticus*) fish fingerlings (Approximately 5 to 8 cm length and 10 – 20 gm weight) were introduced in the stocking tank of greenhouse and acclimation for one week under greenhouse condition. In the period of acclamation, the first two days, the fingerlings were starved for reducing the stress from new environment. After that, the feeding with commercial standard started. The fish fed (32% of Crude protein) was purchased from ARASCO Feed, Saudi Arabia. The fish were feeding thrice a day with the ratio of the 5% of the total weight of fish in each tank. The introduced fish density and weight is provided in Table 4.

Table 4: Initial density and weight of introduced tilapia fish

Unit	Volume of Fish stocking tank (m^3)	Introduced fish density / m^3	No of fishes	Total wage of fish (kg)	Average weight of one fish (gm)
1	7.75*2 = 15.5	100	1540	19.67	12.67
2	7.75*2 = 15.5	120	1860	24.53	13.19
3	7.75*2 = 15.5	140	2170	39.64	18.27

After 7 days of the fish acclimatization, the tomato seedling started in the cultivated area. Directly the tomato seeds were germinated in the same aquaponics water condition. Then, the single seeds were transferred in a cleaned plastic cup of rock wool substrate. The seeds contained rock wool cups directly were inserted in the floating foam sheet in the plant cultivating raceway of aquaponics system. The aquaponics system environment was controlled from pests and ants. Also, the sticky papers were hung surround the cultivated areas for catching the flying pests.

After the germination started, the growth parameter was noted once in every 10 days while the fish counting, and weighing were noted once in two months. The water quality and light intensity were monitored once in a week. The water chemistry was analyzed twice in a month. Also, the data of flowering plants (prune) were charted properly once in 10 days. The pruned leaves were dried and saved for leaves containing profile analyses. Table 5 shows time periods of seeding till harvesting.

Table 5: Seedlings and harvesting periods

Details	Aquaponics Unit 1	Aquaponics Unit 2	Aquaponics unit 3
Seedling	06/12/2016	06/12/2016	06/12/2016
Germination	10/12/2016	10/12/2016	10/12/2016
Flowering	10/01/2017	04/01/2017	08/01/2017
Harvest started	12/03/2017	07/03/2017	08/03/2017
Harvest closed	11/07/2017	06/07/2017	10/07/2017

Figure 2 shows tomato production in greenhouse system, whereas Figure 3 shows fish production in greenhouse system.

Figure 2: Tomato production in greenhouse system

Figure 3: Fish production in greenhouse system

2.4 Water quality parameter analyses

2.4.1 Total ammonia nitrogen

The total Ammonia nitrogen was analyzed by the Ammonia Nitrogen Salicylate TNT method (USEPA, 1999) by using the HACH (USA) manufactured DR900 model multi-parameter calorimeter kit.

2.4.2 Reagents requirement

1. Ammonia Cyanurate Reagent Powder Pillow, 10-mL

2. Ammonia Salicylate Reagent Powder Pillow, 10-mL

2.4.3 Principle

Ammonia compounds were combine with chlorine to form monochloramine. Monochloramine reacts with salicylate to form 5-aminosalicylate. The 5-aminosalicylate was oxidized in the presence of a sodium nitroprusside catalyst to form a blue-colored compound. The blue color was masked by the yellow color from the excess reagent to give a final green-colored solution. The measurement wavelength was 655 nm for spectrophotometers or 610 nm for colorimeters.

2.4.4 Nitrate

The total nitrate was analyzed by the Cadmium Reduction Method (USEPA, 1999) by using the HACH (USA) manufactured DR900 model multi-parameter calorimeter kit.

2.4.5 Principle

Cadmium metal reduces nitrate in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution. The measurement wavelength is 500 nm for spectrophotometers or 520 nm for colorimeters.

2.4.6 Reagent requirement

NitraVer® 5 Nitrate Reagent Powder Pillow.

2.4.7 Nitrite

The total nitrite was analyzed by the USEPA Diazotization method (USEPA, 1999) by using the HACH (USA) manufactured DR900 model multi-parameter calorimeter kit.

2.4.8 Principle

Nitrite in the sample reacts with sulfanilic acid to form an intermediate diazonium salt. This couples with chromotropic acid to produce a pink colored complex directly proportional to the amount of nitrite present. The measurement wavelength is 507 nm for spectrophotometers or 520 nm for colorimeters.

2.4.9 Reagents required

NitriVer® 3 Nitrite Reagent powder pillows.

2.4.10 Iron (Ferrous)

The total nitrite was analyzed by the USEPA-FerroVer® method (USEPA, 1999) by using the HACH (USA) manufactured DR900 model multi-parameter calorimeter kit.

2.4.11 Principle

Ferro Ver Iron Reagent converts all soluble iron and most insoluble forms of iron in the sample to soluble ferrous iron. The ferrous iron reacts with the 1-10 phenanthroline indicator in the reagent to form an orange colour in proportion to the iron concentration. The measurement wavelength is 510 nm for spectrophotometers or 520 nm for colorimeters.

2.4.12 Reagents requirements

FerroVer® Iron Reagent Powder Pillow.

2.4.13 pH, Temperature and Electrical conductivity measurement

The aquaponics water sample pH, Temperature and Electrical conductivity was measured by HACH HQd portable meter (Make: HACH; Model: HQ 40d).

2.4.14 Dissolved oxygen analyses

The aquaponics water contained Dissolved oxygen was measured by Orion star™ and Star plus meter (Make: Thermo Scientific; Model: Orion 4 star).

2.4.15 Alkalinity and acidity

The aquaponics water alkalinity and acidity was measured by the Titration method of APHAstandard methods 2005.

2.4.16 Light Intensity

The green house sunlight transparency Light intensity was measured by the LUX meter (Make: Tekemura; Model: DM – 28).

2.5 Determination of fish growth parameters

The Aquaponics fish were counted once in two months by hand count method and weighed in balance capacity of 75 kg (Model; SD75LOhaus corporation of USA). At the end of the trial, the growth parameters such as survival rate, weight gain, specific growth rate, feed conversion rate, feed conversion efficiency and protein efficiency rate were individually determined by the following equations (Takinay and Davis 2001).

2.6 Quality and quantity of tomatoes

The tomato plant’s shoot and root growth were measured in normal meter scale. The flowering ratio was counted by hand by visual objective. The quantity means none of the tomatoes was counted by hand counting techniques. The size (Height and width) of tomatoes was measured by digitronic calliper machine (Model; 110-DBL series, Moore and Wright products, Camberley).

2.7 Proximate composition and mineral analyses of water and tomato fruits

The aquaponics water samples were taken for mineral nutrient profile analyses twice in every month. The pruned tomato leaf samples were taken once in every month for leaves contain nutrients analyses. Each month harvested tomatoes samples were taken for proximate composition (total protein, total fat, fiber, ash and moisture content) and mineral nutrient content analyses. These tests were analyzed by the university central laboratories in the Animal Nutrition Laboratory. The proximate composition of the tomatoes was analyzed by the method of AOAC, (1995).

2.8 Minerals analysis

By ICP-OES. (Inductively Coupled Plasma Optic Emission Spectroscopy (ICP_OES) Model 710- ES, Varian, United States.

2.8.1 Principle

A known quantity of sample was digested with acids and the solution was aspirated into the plasma generated by inductively coupled plasma source. The atomized elements produce characteristic emission spectral lines, which are separated by a simultaneous optical spectrometer. The concentration of the elements in the solution was deduced from the calibration curve of each element.

2.8.2 Instrumentation

- Varian ICP-OES model 710-ES simultaneous axially viewed plasma with full PC control of instrument settings and compatible accessories was used for the analysis. They feature an innovative megapixel detector designed especially for ICP-OES and provide complete wavelength coverage from 182-766 nm. CEM Mars 5 microwave digestion system was used to extract the elements from the samples. The digestion procedure was based upon the recommendation in USEPA method 3015A guidelines.

2.9 Calculated parameters

Several parameters were calculated as follows by the methods of previously using by Ahmed (2018).

1. Amount of Tomato produced using kg of fish feed = amount of tomato produces/Amount of feed fed

2. Productivity of unit of water in terms of Tomato and fish
    - a. Amount of Tomato produced kg / volume of water used m^3
    - b. Amount of fish produced kg / volume of water used m^3
3. Electricity consumption per unit Tomato and fish production
    - a. Amount of Tomato produced kg / electrical consumption kW
    - b. Amount of fish produced kg / electrical consumption kW

2.10 Statistical analysis

The results were expressed as Mean ± SD. Statistical analysis was carried out by Analysis of Variance (one-way ANOVA) followed by DMRT were considered as indicative of significance, as compared to the control group. All calculations were performed using: SPSS, version 16.0 for Windows (SPSS, Michigan Avenue, Chicago, IL, USA).

Chapter 3: Results

In the present study, each fish compactness growth argument, like weight uniting gain, feed intake, feed conversion ratio, the selection charge per unit and sludge production, is represented in Table 6. According to the present results, the initial weight of fish has not displayed a significant difference between the concentrations. But comparatively initial weight of all handling has significant weight increment. However, the final weight has shown significantly ($P<0.05$) higher in 140 fish/m^3 density the fishes. The same trend has been followed in the weight gain too. The feed intake has shown significantly ($P<0.05$) no difference between the concentration intervention. The FCR values have shown significantly ($P<0.05$) better in high density of fish. The survival rate has shown significantly better performance in low densities of fish treatment.

In the present study, the experimental fish feed, fish and slime proximate composition are represented in Table 7. The provided fish feed was similar in all treatments, so there were not any significant differences ($P>0.05$). Also, the feed fed fishes gaining body proximate composition was as well as same in between treatments, the body proximate composition showed no significant differences ($P>0.05$). The treatments produced sludge proximate compositions also have not shown any significant differences ($P>0.05$) differences between treatments as well.

Table 6: Fish growth parameters in three aquaponics units

	No of Fish Initial	No of fish final	W_1 (g/fish)	W_2 (g/fish)	WG (g/fish)	FI (g)	FCR (%)	Survival rate (%)
100 fish/m^3	1540	1495.33 ± 34.03^{c}	12.70 ± 1.40^{c}	269.42 ± 1.25^{c}	256.72 ± 2.65^{c}	502.50 ± 7.50^{b}	1.87 ± 0.01^{c}	97.86 ± 0.45^{a}
120 fish/m^3	1864	1836.67 ± 16.07^{b}	13.20 ± 2.90^{b}	323.37 ± 31.48^{b}	310.17 ± 28.58^{b}	566.00 ± 25.00^{a}	1.76 ± 0.09^{b}	99.52 ± 0.27^{a}
140 fish/m^3	2176	1958.00 ± 22.91^{a}	18.27 ± 1.63^{a}	410.91 ± 18.81^{a}	392.64 ± 17.18^{a}	544.50 ± 27.50^{a}	1.33 ± 0.01^{a}	91.13 ± 0.41^{b}

Each value is a mean ± SD of three replicate analyses, within each column means with different superscripts letters are statistically significant $P<0.05$ (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied).
W_1 – Initial weight of one fish; W_1 – Final weight of one fish; WG – Final weight gain of one fish; FI – Feed intake of one fish
FCR – Feed conversion ratio of one fish.

Table 7: Proximate composition of fish feed, fish and the fish produced sludge

Factor	Fish density	Moisture	Ash	Crude Protein	Crude Fat	Crude Fibber	CHO	Energy
Feed	Same feed to fed all unit	10.50±0.50	10.83±0.76	38.13±0.71	3.44±0.15	10.30±1.00	37.71±0.45	1.25±0.12
Fish	100/m^3	74.66±1.69 ^{a}	12.11±0.85 ^{a}	52.52±1.12 ^{a}	1.62±0.12 ^{a}	29.56±1.50 ^{a}	4.16±0.81 ^{a}	2.49±0.04 ^{a}
	120/m^3	75.38±1.17 ^{a}	11.85±0.50 ^{a}	52.28±1.06 ^{a}	1.72±0.03 ^{a}	29.75±1.49 ^{a}	4.64±0.03 ^{a}	2.48±0.05 ^{a}
	140/m^3	73.98±0.65 ^{a}	12.27±0.63 ^{a}	53.32±0.34 ^{a}	1.61±0.11 ^{a}	29.00±0.70 ^{a}	4.03±0.73 ^{a}	2.39±0.14 ^{a}
Sludge	100/m^3	10.17±0.76 ^{a}	25.77±1.63 ^{a}	25.98±0.32 ^{a}	5.51±0.84 ^{a}	2.95±0.13 ^{a}	39.79±1.30 ^{a}	1.10±0.04 ^{a}
	120/m^3	10.17±0.76 ^{a}	25.70±1.66 ^{a}	26.06±0.20 ^{a}	5.08±0.11 ^{a}	3.05±0.19 ^{a}	39.70±1.31 ^{a}	1.08±0.06 ^{a}
	140/m^3	10.00±0.50 ^{a}	24.40±0.85 ^{a}	25.39±0.99 ^{a}	5.92±0.75 ^{a}	3.07±0.15 ^{a}	40.72±0.8 ^{a}	1.07±0.05 ^{a}

Each value is a mean ± SD of three replicate analyses, within each column means with different superscripts letters are statistically significant $P<0.05$ (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied.

The present investigation provided the different density of fish culture in aquaponics unit treatment and total quality parameter in Table 8. The pH rate was significantly high in high density (140 fish/m^3) treatment in comparison to other treatments. The temperature level showed no significance difference from initial to final level. The electrical conductivity was significantly ($P<0.05$) improved from initial to final treatments. The total dissolved solids are significantly increased in 120 fish/m^3 treatment followed by the low density fish treatments. Ammonia, nitrate and nitrite level was significantly ($P<0.05$) improved from initial level, but no significance difference was found in between treatments. Alkalinity level was maintained by $CaCO_3$ and the dissolved oxygen level did not show any significance differences ($P>0.05$) from initial to final day of experiments.

In the present study, the aquaponics fish effluent water sample was analyzed for determining the level of micro and macro nutrients level. The results are provided in Table 9. In this experiment, the Ca level was significantly ($P<0.05$) improved from initial to final; but no any significant differences ($P>0.05$) variance in-between treatments. The Fe level showed better significant improvement in all treatment water when compared with initial. As well as the other minerals like K, Mg, Mn, Mo, P, S and Zn level which showed significant improvement in fish treatment effluent water, the significance difference ($P>0.05$) showed no variation between treatments.

Table 8: Average water quality parameters of aquaponics effluent in aquaponics systems

	pH	**Temperature**	**EC mV**	**TDS ppm**	**Ammonia**	**Nitrate**	**Nitrite**	**Alkalinity**	**DO mg/l**
Initial	6.47±0.21^{b}	24.89±3.97^{a}	22.20±1.76^{b}	136.00±18.65^{c}	0.03±0.01^{b}	0.07±0.01^{b}	0.01±0.00^{b}	12.86±1.46^{b}	5.09±0.13^{a}
100 fish/m^{3}	6.37±0.08^{ab}	25.00±3.51^{a}	35.51±5.21^{a}	384.78±86.61^{b}	0.60±0.37^{a}	17.37±5.07^{a}	0.23±0.07^{a}	36.28±6.24^{a}	4.77±0.36^{a}
120 fish/m^{3}	6.42±0.12^{ab}	25.18±3.47^{a}	39.44±10.23^{a}	504.86±93.36^{a}	0.95±0.69^{a}	21.81±6.98^{a}	0.26±0.17^{a}	37.62±6.66^{a}	4.88±0.29^{a}
140 fish/m^{3}	6.55±0.14^{a}	25.13±3.53^{a}	36.21±8.54^{a}	422.89±94.01^{ab}	0.63±0.55^{a}	16.20±5.83^{a}	0.17±0.09^{a}	38.82±6.02^{a}	4.82±0.29^{a}

Each value is a mean ± SD of three replicate analyses (Eight-month replicate average), within each column means with different superscripts letters are statistically significant P<0.05 (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied).

Table 9: Macro and micro elements concentration in fish effluent water (mg/l)

	Ca	**Fe**	**K**	**Mg**	**Mn**	**Mo**	**Na**	**P**	**S**	**Zn**
Initial	34.10±3.03^{b}	0.017±0.00^{b}	5.05±0.83^{b}	3.77±0.24^{b}	0.009±0.00^{a}	0.018±0.00^{a}	43.77±1.09^{c}	1.15±0.17^{b}	3.33±0.20^{b}	0.01±0.00^{b}
100 fish/m^{3}	59.65±20.09^{a}	0.75±0.62^{a}	10.66±7.20^{a}	23.04±22.53^{a}	0.009±0.00^{a}	0.018±0.00^{a}	61.60±19.61^{ab}	1.97±0.75^{a}	35.18±41.25^{a}	1.01±0.94^{a}
120 fish/m^{3}	57.47±17.59^{a}	0.61±0.52^{a}	7.59±4.26^{a}	14.56±12.68^{a}	0.016±0.01^{a}	0.018±0.00^{a}	57.77±12.89^{a}	1.64±0.64^{a}	19.12±21.99^{a}	0.77±0.66^{a}
140 fish/m^{3}	52.79±18.17^{a}	0.76±0.50^{a}	7.24±5.83^{a}	18.27±26.65^{a}	0.021±0.02^{a}	0.018±0.00^{a}	59.14±18.24^{ab}	1.43±0.61^{a}	26.60±51.88^{a}	0.94±0.61^{a}

Each value is a mean ± SD of three replicate analyses (Eight-month replicate average), within each column means with different superscripts letters are statistically significant P<0.05 (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied).

In the present study, the tomato production quality and quantity are represented in Table 10. The length of the experimental period was seven and half months. In tomato fruit production,120 fish/m^3 treatment produced significantly higher yield of tomato fruit followed by the 100 fish/m^3 and 140 fish/m^3 treatment aquaponics system. The same trend was followed in tomato fruits numbers and single tomato plant yield. The physical quality of tomato means height, weight and width showed no significant variations in-between treatments. Comparatively, 120 fish/m^3 aquaponics system produced better yield than others. The results showed that the average monthly production did not have a significant difference ($P>0.05$) between the treatments, but relatively, 140 fish/m^3 showed a decrease in tomato production.

In the present study, the harvested tomato fruits proximate composition is represented in Table 11. The proximate composition like moisture, dry matter, ash, crude protein, fat and carbohydrate levels did not show any significant ($P>0.05$) variation between treatments. The study also provides different densities of fishes handling in an aquaponics system produced tomato, including analyses of total mineral contents. The total mineral food composition is provided in Table 12. This result showed that there was no significant difference ($P>0.05$) between treatments of the total proximate composition and mineral composition.

Table 10: Total tomato production and physical quality

Aquaponics Unit	Total quantity (kg)	Total no of fruits (No’s)	Yield / plant (Kg)	Average Weight (gm)	Average Height (mm)	Average width (mm)
100 fish/m^3	2371.72±204.76^b	120406.01±2428.40^b	6.93±0.60^b	19.69±1.43^a	28.40±0.98^a	32.82±1.01^a
120 fish/m^3	2627.05±183.05^a	152959.19±14795.58^a	7.68±0.54^a	18.56±0.69^a	28.27±0.32^a	32.05±0.67^a
140 fish/m^3	2168.84±135.12^c	119922.25±15013.72^c	6.34±0.40^c	19.37±1.76^a	27.35±0.96^a	31.69±1.84^a

Each value is a mean ± SD of three replicate analyses (Five-month replicate average), within each columns means with different superscripts letters are statistically significant $P<0.05$ (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied).

Table 11: Total proximate composition of harvested tomato fruit (%)

Fish Density	Moisture	Dry matter	Ash	Crude protein	Crude Fibber	Fat	Carbohydrate
100 fish/m^3	92.25±0.38^a	7.75±0.38^a	8.05±0.36^a	20.11±0.87^a	15.10±0.39^a	3.52±0.18^a	53.23±0.62^a
120 fish/m^3	92.92±0.19^a	6.79±0.43^a	8.36±0.76^a	19.85±1.41^a	13.65±0.99^a	3.53±0.38^a	54.62±2.58^a
140 fish/m^3	92.30±0.31^a	7.37±0.66^a	8.65±0.58^a	19.05±1.16^a	13.67±1.77^a	3.52±0.39^a	55.11±3.71^a

Each value is a mean ± SD of three replicate analyses, within each columns means with different superscripts letters are statistically significant $P<0.05$ (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied).

Table 12: Macro and micro nutrients level in tomato fruit (mg/g)

Fish Density	Ca	Mo	Mg	Na	P	S	K	Cu	Fe	Mn	Zn
100 fish/m^3	1962.28± 180.38^a	1.95± 0.87^a	965.41± 69.88^a	788.82± 165.46^a	5034.29± 158.05^a	1739.74± 159.17^a	15623.18± 278.44^a	8.57± 0.44^a	67.34± 5.25^a	11.44± 0.87^a	28.54± 2.35^a
120 fish/m^3	1850.21± 60.53^a	1.37± 0.26^a	991.60± 36.96^a	874.88± 49.94^a	5125.68± 338.45^a	1470.80± 98.39^a	15677.54± 345.75^a	8.94± 0.68^a	70.57± 4.19^a	11.96± 1.10^a	28.21± 1.76^a
140 fish/m^3	1991.50± 165.09^a	1.27± 0.10^a	1085.89± 84.63^a	1054.52± 160.01^a	5211.05± 270.16^a	1442.60± 81.20^a	16282.02± 854.80^a	9.80± 0.79^a	71.84± 9.36^a	12.74± 0.39^a	30.78± 0.96^a

Each value is a mean ± SD of three replicate analyses, within each columns means with different superscripts letters are statistically significant $P<0.05$ (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied).

In this study, different densities of fish, tomato growing periods, and water and electricity consumption are provided in Table 13. For eight months, water consumption and electricity consumption showed significant differences ($P<0.05$) in high intensity of fish processing including tomato cultivation in the aquaponics unit. The water flow rate showed no significant differences ($P>0.05$) in each treatment. Each transaction is presented in the Equinox unit inputs (water, electricity, feed use) and outputs (fish, tomato and sludge production) in Table 9. The input and output ratio reports showed much better performance in 120 fish/m^3 and 140 fish/m^3 followed by 100 fish/m^3. Figure 4 shows monthly average tomato fruit production. The total tomato production was better in 120 fish/m^3 followed by 100 fish/m^3 as shown in Figure 5. The total fish production was better in 140 fish/m^3 (Figure 6).

In the present experiment, the input materials like feed, water and electricity based fish and tomato production is represented in Table 14. The total fish production is significantly higher in high density (140 fish/m^3) fish introduced treatment followed by the 120 fish/$m^3$and 100 fish/m^3. The tomato fruits production was significantly higher in high density (120 fish/m^3) fish introduced treatment followed by the 100 fish/m^3 and 140 fish/m^3. The feed utilization is significantly higher in high density (140 fish/m^3) fish introduced treatment followed by the 120 fish/m^3 and 100 fish/m^3. The input material electricity based tomato production was significantly higher in 140 fish/$m^3$and 120 fish/m^3 treatment system, but the tomato fruit production was significantly higher in 120 fish/m^3 followed by the 100 fish/m^3 and 140 fish/m^3 treatments. The same trend was followed in the water and feed based tomato fish production.

Table 13: Water and electric consumption for aquaponics unit, cooling system and water flow rate

Fish density	Monthly water consumption (US gallons)	Evaporation (US gallons)	Water usage for cooling system (US gallons)	Electric Usage (K.wh)	Water flow rate (Fixed) (m^{3}L/hour)
100/m^3	156.03±23.48^{a}	156.03±23.48^{a}	439.98±9.89^{a}	11,887.40±307.59^{a}	10^{a}
120/m^3	146.67±17.21^{a}	149.31±17.74^{a}	457.49±25.18^{a}	11,869.90±283.54^{a}	10^{a}
140/m^3	177.90±15.87^{a}	164.60±9.60^{a}	443.74±37.98^{a}	11,867.57±306.07^{a}	10^{a}

Each value is a mean ± SD of three replicate analyses, within each columns means with different superscripts letters are statistically significant $P<0.05$ (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied).

Table 14: Water, electricity and feed consumption for the production of fish and tomato fruit (input and output ratio)

Fish density	Total fish production (Kg)	Total Tomato production (Kg)	Feed utilized (kg)	Each unit of Electric production (kg)		Each m^3 of water production (kg)		Each kg of feed production (kg)	
				Fish	Tomato	Fish	Tomato	Fish	Tomato
100/m^3	421.83±15.00^{c}	2371.72±204.76^{b}	867.33±24.11^{b}	0.034^{b}	0.196^{b}	26.13^{c}	40.28^{b}	0.466^{c}	2.62^{a}
120/m^3	626.67±27.54^{b}	2627.05±183.05^{a}	1050.33±24.50^{ab}	0.052^{a}	0.222^{a}	38.70^{b}	44.40^{a}	0.571^{b}	2.45^{a}
140/m^3	783.33±32.53^{a}	2168.84±135.12^{c}	1110.00±27.84^{a}	0.053^{a}	0.139^{c}	52.58^{a}	36.50^{c}	0.754^{a}	1.96^{b}

Each value is a mean ± SD of three replicate analyses, within each column means with different superscripts letters are statistically significant $P<0.05$ (one-way ANOVA and subsequently *post hoc* multiple comparison with DMRT applied).

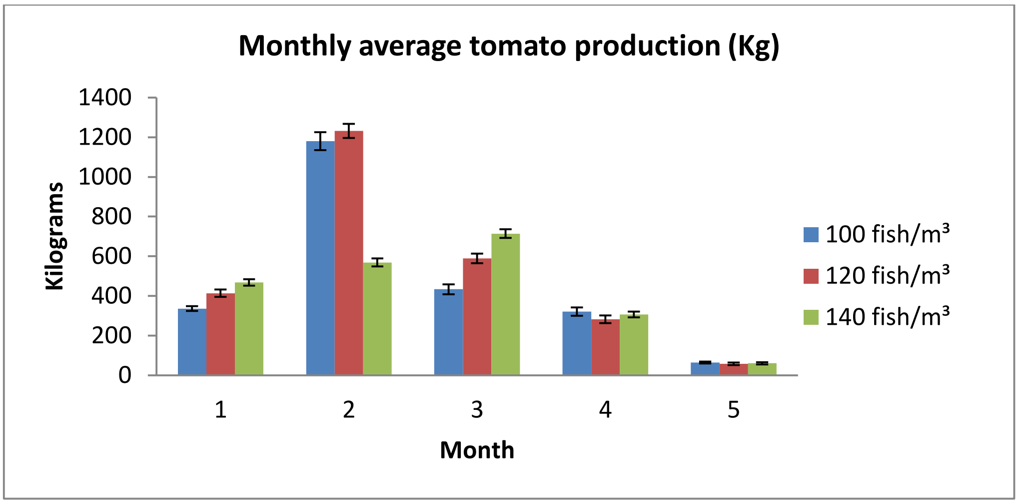

Figure 4: Monthly average tomato fruit production (bars represent SD)

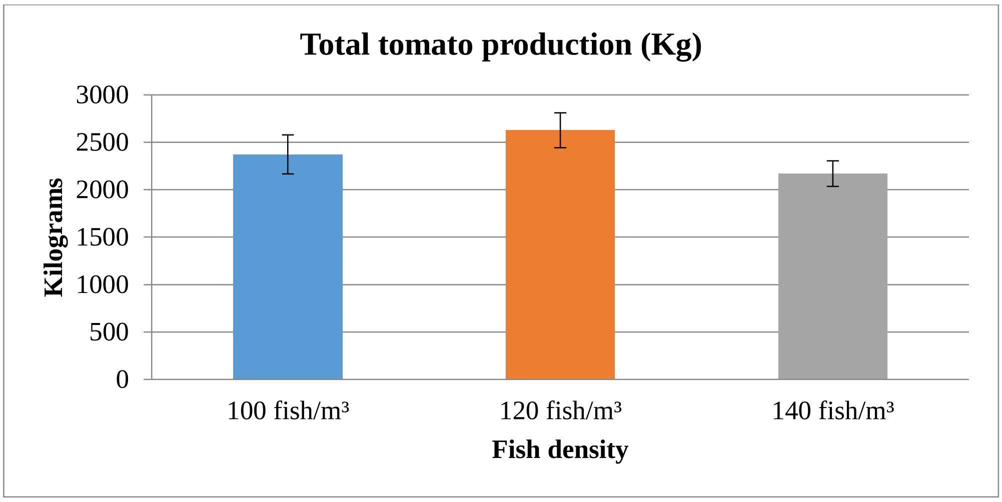

Figure 5: Total tomato production (bars represent SD)

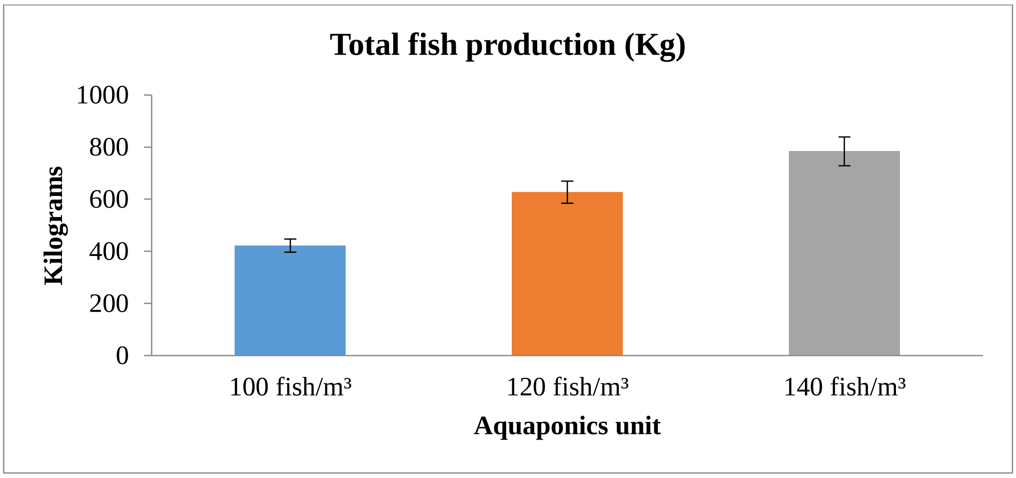

Figure 6: Total fish production (bars represent SD)

Chapter 4: Discussion

In the present study, the aquaponics systems were operated with different densities of tilapia fish 100 fish/m^3, 120 fish/m^3 and 140 fish/m^3. The treatment was tested and the water flow rate regulated the range of 10 m^{3}L/h to the plant cultivation raceway from the biological filter tank. The tabulated results are discussed as follows.

4.1 Fish growth parameters and production

For the present study, the fish Nile tilapias were introduced into the fish stocking tank in the aquaponics system at the density of 100 fish/m^3 in aquaponics unit 1; 120 fish/m^3 in aquaponics unit 2; and 140 fish/m^3 in aquaponics unit 3. The initial weight unit was similar in all systems. The final weight gain was significantly higher in high density fish aquaponic unit (140 fish/m^3). As well as, the feed intake and feed conversion ratio also were significantly higher in high density fish treatment. However, the survival rate was significantly higher in low density aquaponics unit. The prolonged experimental periods, in all treatment fishes were fed with same feed for all the treatment, FCR value also nearest same. Apart from this, fish production means that aquaculture was much higher in 140 fish/m^3 density unit. The result showed that the high density of fish survival rate was slightly affected, but FCR food intake and production was better with this treatment than low-density fish. The present results revealed that the high density of tilapia cultivation, gave better yield of fishes with low feeding rate. These results agree with the study done by Ahmed and Hamad (2013). Who reported that the increased storage density of 100 to 200 m^3 fish in the fish tank had a negative impact by limiting survival, growth and benefits. According to their statement, the high density that affects the survival rate of 140 fish/m^3 has been affected, but growth was relatively better than other low-density stocking. On the other hand, another study conducted by El-Saidy and Hussein (2015) on the effect of low stocking density (50 fish m^3) revealed a positive effect on growth performance and feed utilization parameters. However, farmers and commercial producers always look for optimum storage density to maximize profits. Finally, according to Salam *et al*., (2014), it can be concluded that the ideal storage density was 100 m^3 fish and protein food levels was 25%, so that maximum growth was achieved with higher analysis of the profit.

4.2 Proximate composition of feed, fish and sludge

In this current study, the different densities of fish, fish feed and the fishes produced sludge proximate composition were examined. For this experiment, all treatments were fed with the same feed (36 – 38% protein). The feeding rate and FCR were also as well as same in all treatments. However, the same feed fed all treatment fishes proximate composition such as, moisture, ash, crude protein, fat, fiber, carbohydrate levels showed no significant differences between all treatments. Also, the same trend was followed in sludge proximate composition. The results revealed that the feed did not affect the fish proximate composition and growth impact. Because, in all treatment fishes fed with the same feed. Next, the feed and frequency ratio vary depending on the type of fish. In aquaponics systems, storage density must be improved to ensure that the waste was converted to ammonia and nitrate in the final phase. Through optimum stocking density, one can obtain maximum production without effects on environment, optimum health, economic benefits (Rahman and Marimuthu, 2010) and minimum occurrence of physiological and behavioral disorders (Ashley, 2007; Ayyat *et al*., 2011). The present findings were similarly agreed with Rahman, (2005) Ridha (2005), Gibton et al., (2008), Rashid (2008) Alam, (2009), Rahman and Marimuthu, (2010) and El-Salam et al., (2014). They suggested that the increase of fish stocking density is produced high yield in same amount of feed in comparison with lower densities of fishes. Higher density produced better yield and lower density produced only size increment and lower FCR. The present results are agreed with Ahmed and Hamad (2013) in their statement, there was an increase in stocking density from 100 to 200 fish/m^3 in the fish tank which resulted in negative impact by reduced survival, growth and benefits. On the other hand, another study conducted by El-Saidy and Hussein (2015) about an effect of low stocking density (50 fish/m^3) inferred that there was a positive effect on growth performance and feed utilization parameters. However, farmers and commercial producers always look for the optimum stocking density to achieve maximum profits.

4.3 Aquaponics water quality parameter and mineral nutrient concentration

During the period of experiment, the aquaponics water was examined monthly thrice. The present investigation provided the different density fish culture in aquaponics unit treatment and quality parameter in Table 8. The pH rate was significantly high in high density (140 fish/m^3) treatment in comparison with other treatments. The temperature level showed no significance difference from initial to final level. Because, the temperature was regulated with the help of water cooling radiators technology. The cooling fan was attached with the thermo-regulator sensor; when the temperature was down or high and the fan was automatically started and maintained the temperature was inside of aquaponics system. The electrical conductivity was significantly increased from initial to final treatments. The total dissolved solids were significantly increased in 120 fish/m^3 treatment followed by the low density fish treatments. The aquaponics effluent water contained total ammonia, nitrate and nitrite level significantly was increased when compared with initial water quality. However, with treatments with different density fishes, showed no difference. The results revealed that the increments of chemical substances we obtained from fish waste. So, the water chemical parameters increased when compared with initial level. The nitrate increment is indication of better working condition of bio filter mechanism.

Alkalinity level was maintained by adding of $CaCO_3$, so, the level was regulated as per standard. Dissolved oxygen level also maintained with the supply of electric air blower. So, it was maintained as standard level as throughout of the experimental period. In the present study, the aquaponics fish effluent water sample was analyzed to determine the level of micro and macro mineral nutrients level. The results are provided in Table 9. In this result the Ca level was significantly improved from initial to final; however, no significant variance in-between treatments. As well as the other minerals like K, Mg, Mn, Mo, P, S and Zn level showed significant improvement in fish treatment effluent water. Water quality parameters such as, temperature, DO, pH and total ammonia, nitrite and nitrates of the water were within the adequate range for raising the experimental Tilapia *Oreochromis niloticus* (Wheaton *et al*., 1994). The present results were similarly agreed with Saufie *et al*., (2015). The number of the nitrifying bacteria (Nitrosomonas and Nitrobacter) increased with time to keep the increasing levels of ammonia production from growing fish within safe levels which indicates a successfully active biological filter.

The slight increment of pH, TDS and EC also had no effect within the range of the aquaponics water quality (FAO, 2014). The results of the current study came in line with the statement of Rakocy *et al*. (2006), Somerville *et al*. (2014), Wortman and Dawson, (2015) and Zou *et al*. (2016). Also, the results of the aquaponics units (water, temperature) agreed with the following statement: "When the ideal temperature is not maintained in fish tanks, the growth is drastically reduced and causes diseases which result in other criticalities such as reproduction reduction, sluggishness due to retarded digestion and capacity of fishes" (Bailey and Alanara, 2006). The ideal temperature for vegetable growth was 20 - 25 °C and for bio-filters (nitrifying bacteria) it ranged from 25 to 30 °C while tilapia died when the temperature dropped below 10°C (Edaroyati *et al*., 2017).

4.4 Tomato production and nutrient proximate composition

In this work, each aquaponics system produced tomato fruits harvested by weekly twice some time thrice. Monthly average tomato fruit yield showed no statistical significant in between treatments. However, the total tomato production was significantly higher in 120 fish/m^3 in aquaponics treatment unit, followed by 100 fish/m^3 and 140 fish/m^3 fish treatment unit. The high density fish treatment (140 fish/m^3) and low density treatment (100 fish/m^3) produced low yield of tomato fruits. The mid density (120 fish/m^3) produced better yield. So, the mid density was effective for tomato production. However, the physical quality such as, height, weight and width did not show any significant difference between treatments. The present results revealed that the densities are not affecting the physical quality of tomato fruits, but it also affected the production. In addition, the tomato fruits total proximate composition (Dry matter, ash, moisture, total protein, carbohydrate and lipid) and mineral nutrients components. The proximate composition and mineral nutrient were similar in all treatments, were analyzed its showed no any significance variance in-between treatments. The present result revealed that the fish density was not affected the physical and chemical quality of tomato fruits. The investigation came in line with the findings of Salam *et al*. (2014) while the finding of proximate composition of tomato fruit agreed with Hernandez Suarez *et al*. (2007) and Pinho *et al*. (2011). The finding of mineral nutrient composition agreed with the findings of Higashide. (2013) and Schmautz *et al*. (2016).

4.5 Water, electricity and feed consumption based fish and tomato production

In the present study, the different densities of fish treatment aquaponics units input materials consumption such as, water, electricity and feed were recorded. The plant cultivation raceway water level was checked regularly and, if the water level was low the fresh water was directly added in the raceway. The throughout period of the experiment the water consumption for plant cultivation and cooling system maintenance showed no significance difference in between treatments. As well as, the electrical consumption also showed no difference in between treatments. But, the feed consumption was significantly higher in high density treatments like 140 fish/m^3 and 120 fish/m^3 aquaponics unit. Because, the fish densities were very high. So, the feed consumption was simultaneously increased.

In current work, the input materials like water, electricity and feed based output (Fish and Tomato) are provided in (Table 14). Based on the electric consumption, the fish production was significantly higher in high density (140 fish/m^3 and 120 fish/m^3) treatments, the tomato production was significantly higher in 120 fish/m^3 treatment followed by the other. Based on the water consumption the fish production was significantly higher in 140 fish/m^3 treatment and followed by the other treatments, the tomato production was significantly higher in 120 fish/m^3 and lower in high density treatment (140 fish/m^3). Based on the feed consumption, the fish production was significantly higher in 140 fish/m^3 treatment and followed by the other treatment, the tomato production was significantly higher in 120 fish/m^3 and lower in high density treatment (140 fish/m^3). These findings were similar to previous reported values for single populations of tilapia vegetable production (Al Hafedh, 1999; Shnel *et al.,* 2002; Rakocy *et al.,* 2006; Love *et al.,* 2015a, b; Tokunaga *et al.,* 2015).

Agriculture is one of the major users of fresh water globally and the water is essential for fish and plant growth. In the present study, the fish density either high or low water usage was similar in all treatments. There was no any water wastage and the physico-chemical parameter indicated that the density of fish also was not affected the by water quality. While aquaponics offers a water-efficient method for both aquaculture and hydroponics, in a previous survey of 809 aquaponics operations, 90% of respondents used drinking water (community piped water or well water) as their water source for aquaponics (Love *et al.*, 2014). The daily water loss of about 1% was near the expected range of 0.5–10% reported previously (Rakocy *et al.,* 2006). Energy demand and access to electricity are limitations of small-scale aquaponics (Somerville *et al., 2014*). In a survey of commercial aquaponics operators, those in temperate to warm cli-mates were four times as likely to be profitable as those in colder climates (Love *et al.*, 2015a, b), suggesting that heating costs could be a constraint. Over 70% of commercial systems are sited in a greenhouse or use a greenhouse in combination with other growing locations such as indoors or outside (Love *et al.,* 2015a, b).

Aquaponics has been discussed as a part of sustainable intensive agriculture; however, there are several limitations to aquaponic food production that may make aquaponics a better or worse fit at certain scales or in some climates or regions of the world. The increase in cherry tomato productivity by using fish effluent can especially aid small farmers in developing countries. In arid regions, water scarcity should be considered when designing any farming system. Therefore, in an integrated system, where the water used for fish growth was subsequently used for crop irrigation, water was certainly used more efficiently. When associated with water reuse, an increase in productivity was reached, it becomes even more evident the importance of integrating aquaculture with agriculture. These benefits must outweigh the limitations for aquaponics to be economically viable for the farmer, environmentally sustainable, and beneficial for the community. These data can help fill gaps on energy use in aquaponics, serve as a point of comparison to other small-scale aquaponic systems in other regions with different climates, inform farm business plans, and serve as a starting point for future work on systems level studies of aquaponics.

Chapter 5: Conclusion

The quality and quantity of the production of tilapia and tomato using the aquaponic system was studied in this system. Although the limited use of the system in the region this study showed potential productivity and profitability. The effect of different densities of fishes like 100 fish/m^3, 120 fish/m^3 and 140 fish/m^3 fish stocking density was studied as well with the cultivation of tomato.

The quantity and quality of the yields from the system was analyzed using different test methods. The fish quality was confirmed by the way of feed utilization, feed conversion ratio, survival rate, and weight gain and body proximate composition. In the fish growth parameters like weight gain, feed intake and feed conversion ratio were significantly higher in high density (140 fish/m^3) treatment comparison to other treatment. However, the different densities fish contained nutrient proximate composition (Ash, moisture, dry matter, crude protein, lipid, fiber and carbohydrate) and minerals composition also showed no significant difference in between treatments. Based on the feed intake and FCR value the high density treatment fishes showed better result in the production of fish.

The physicochemical quality such as, temperature, dissolved oxygen, pH, electrical conductivity, total dissolved solids, total ammonia, total nitrogen, nitrate and alkalinity level was evaluated. In the physicochemical parameter temperature level was regulated by the mechanical cooling system and dissolved oxygen maintained by the mechanical air blower; so, it regulates as same trend in prolong the period of experiment. Others parameters like pH, ammonia, nitrate, nitrite, electrical conductivity and total dissolved solids are significantly improved in all treatments when compared with initial. But, in between treatments showed no significant difference. The results revealed that the fish densities are not affected by the recirculation water physicochemical quality.

Furthermore, to confirm the quality and quantity of the produced tomato fruits nutritional components ratios were investigated. The tomato fruits physical quality such as, weight, height and width showed no significance difference in between treatments. But the production of fish was significantly higher in 140 fish/m^3 treatment followed by the 120 fish/m^3 and 100 fish/m^3 treatments. The proximate composition namely moisture, crude protein, crude fat, crude fiber, carbohydrates, total energy and total mineral content also showed no significant differ in all treatments. The present results revealed that the density of fishes was not affected by the quality of tomato fruits. In the tomato production the 120 fish/m^2 treatments showed better yield.

At last, the water and electrical consumption was recorded in all treatments. The electricity and water consumption showed no significance difference in all treatments. The consumption and usage was similar in all density treatments. The input materials (water and electricity) based production showed better fish yield in 140 fish/m^3 and the better tomato yield in 120 fish/m^3 treatment.

Finally, the results of this study revealed that the high density of fish feed (140 fish/m^3) resulted in increased production of tilapia significantly, but fish production was relatively low with 120 fish/m^3 followed by 100 fish/m^3 treatment. Fish density also does not affect water quality, near-fish composition, and approximate tomato composition. High density (140 fish/m^3) of fish does not affect tomato composition. The second treatment 120 fish/m^3 significantly increased the fruits of tomatoes. The main objective was to produce tomato-assisted fish farming system aquaponics under UAE climate condition. Thus, it can be observed that the second density (120 fish/m^3) was very effective and suitable for aquaponics systems in the UAE agriculture case. The revealed results concluded that the second fish density of 120 fish/m^3 was useful for fish farming (vegetable and fruit farming) for sustainable and prosperous recirculation aquaculture in UAE.

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