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Department of Aridland Agriculture

DETERMINATION OF THE IDEAL PLANT DENSITY OF TOMATO SOLANUM LYCOPERSICUM UNDER AN AQUAPONIC PRODUCTION SYSTEM WITH TILAPIA OREOCHROMIS AUREUS UNDER UAE CONDITIONS

Mohamed Ahmed Al Dhanhani

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

Under the Supervision of Dr. Shyam S. Kurup

April 2018

Declaration of Original Work

I, Mohamed Ahmed Al Dhanhani, the undersigned, a graduate student at the United Arab Emirates University (UAEU) and the author of this thesis entitled "*Determination of the ideal plant density of tomato Lycopersion esculentum under an aquaponics production system with tilapia Oreochromis niloticus under 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. Shyam Krup, in the College of Food and Agriculture at UAEU. This work has not previously been presented or published or formed the basis for the award of any academic degree, diploma under 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 Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions.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 and/or publication of this thesis.

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Abstract

Aquaponics is an agricultural system that saves water and fertilization and offers a way of growing plants without soil pest infestation or pesticide residues. This system ensures the production of hazardous chemical free food for humans. This system also ensures sustainability by creating a natural relationship between fish and plants and makes gardening more productive and economical.

Aquaponics system is a dynamic ecosystem that can be integrated to achieve food security through the production of fish and vegetables without the intervention of fertilizers.

The focus of this study is optimizing planting density of tomato in an aquaponics system, with assess the production of Nile tilapia (Oreochromis aureus) and tomato (Solanum lycopersicum) in the aquaponic system with different fish density. The experiment implemented under greenhouse condition at the College of Food and Agriculture at Falaj Hazza Campus Al Ain, UAE. Three densities of tomato plants (2, 3 and 4 plants in foam) and three densities of tilapia (100, 120 and 140 kg/m^3) were used. The evaluation of the production system was based on the flowering behavior, tomato yield production and its quality as well as fish growth rate. Tomato fruit samples were analyzed for the chemical quality which includes dry matter, moisture, crude protein, fat, crude fiber, ash%, macro and micro nutrients levels. The investigation also focus on optimum fish stocking density and total yield of tomato in the aquaponics system. Fish density affected the fish growth parameters and the most densiest group showed the best results in terms of fish growth. As for production of tomato plant and its quality and chemical content recorded its best with using 2 plants in the dishes. So, under the same conditions of this experiment to improve the density of fish and obtain a higher density of tomato plant in the system of aquaponics can be achieved when the use of two plants in the dishes under the highest thickness of 140 kg/m^3.

Keywords Tomato, density, growth, fish stocking density, aquaponics, water, chemical analysis, elements.

Title and Abstract (in Arabic)

تحديد الكثافة المثلى لزراعة نبات الطماطم في نظام الزراعة المائية المختلطة بدون تربة (أكوابونيك) مع سمك البلطي تحت ظروف دولة الإمارات العربية

الملخص

نظام الأكوابونيك يحل الكثير من المشاكل الزراعيه، وخاصة مشاكل المياه والإخصاب، لذلك يوفر طريقه لزراعة النباتات دون خوف من الإصابه بأفات التربه أو سموم المبيدات، ولا يحتاج إلى زراعه النباتات وهذا النظام يعتبر أفضل الطرق لإنتاج نباتات خاليه من المواد الكيميائيه الخطره و تكون صحيه على صحة الانسان، ومن جهه أخرى يضمن بيئه طبيعيه بين الأسماك والنباتات ويجعل البستنه أكثر انتاجيه واقتصاديه.

يعتبر نظام الاكوابونيك نظام بيئى ديناميكى يمكن الاعتماد عليه لتحقيق الاكتفاء الذاتي من خلال انتاج المحاصيل الغذائيه سواء سمكيه او خضريه دون اسمده او ملوثات.

تهدف هذه الاطروحه الى دراسة كثافه الزراعه المثلى للطماطم في نظام الاكوابونيك واستهلاك المياه والكهرباء في النظام. تم تنفيذ التجربه تحت ظروف البيوت البلاستيكيه في كليه الاغذيه والزراعه فلج هزاع في منطقه العين، الامارات العربيه المتحده. ثلاث كثافات من الطماطم (2، 3 و4 نباتات في الاطباق الفلينيه) وثلاث كثافات من السمك البلطى (100، 120 و140 كجم / م^3). واعتمد التقييم على عدد الازهار وانتاج الطماطم ونمو الأسماك. اخذت عينات من ثمار الطماطم لتقدير (الماده الجافه، الرطوبه، البروتين، الدهون، الالياف، الرماد، نسبه العناصر الكبرى والصغري).

تحت نفس الظروف من هذه التجربه لتحسين كثافه الأسماك والحصول على اعلى كثافه لنبات الطماطم في نظام الاكوابونيك يمكن تحقيق ذلك عند استخدام نباتين في الاطباق الفلينيه تحت أعلى كثافه سمكيه 140 كجم / م^3.

مفاهيم البحث الرئيسية: الطماطم، الكثافة، النمو، كثافة تخزين الأسماك، aquaponics، الماء، التحليل الكيميائي، العناصر.

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Dedication

To my beloved parents and family

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List of Abbreviations

Aw	Water activity
CFU	Colony-forming unit
DSC	Differential scanning calorimetry
ICP-OES	Inductively coupled plasma atomic emission spectroscopy
kPa	Kilo Pascal unit
LAB	Lactic acid bacteria
NaCl	Sodium chloride (table salt)
pH	Hydrogen ion concentration
Tg	Glass transition temperature
UF	Ultrafiltration

Chapter 1: Introduction

The increasing population and the subsequent increasing need for food necessitates the effective use of water resources (Sahin *et al.*, 2016). Therefore, employing alternative food production systems in agriculture are of paramount importance (Saha *et al*., 2016). One of the main challenges of agriculture in the 21st century is the need to feed the growing population by finding more efficient and sustainable food production systems that not only suits the local climate but the envisaged climate change. There is a lack in the availability of freshwater and cultivable land to increase the crop yields without affecting the environmental (FAO, 2009). To overcome global problems such as water scarcity, soil degradation, climate change and the population increase the aquaponics system appears to be an alternative solution. Aquaponics is the combination of aquaculture (raising fish) and hydroponics (the soil-less growing of plants) that grows fish and plants together in one integrated system (Yıldız and Bekcan, 2017). The aquaponics system is an environmental friendly and sustainable food production system (Tyson *et al.,* 2011 and Salam *et al*., 2013).

Aquaponics, the symbiotic association of fish and vegetables in recirculating water systems is emerging as one of the most important areas of sustainable agriculture. With aquaponics the dual production of fish and plants is possible by using the water from the fish tanks circulated for plant growth. The essential elements of an aquaponics system consists of fish rearing tank, a suspended solid removal component, a bio-filter, hydroponics component and a sump. In the aquaponics system, the nutrients generated by microbial breakdown of organic wastes excreted by the fish are absorbed by plants cultured hydroponically (Rakocy *et al*., 2006). Through microbial decomposition the insoluble fish metabolite and unconsumed feed are converted into soluble nutrients which then can be absorbed by plants (Rakocy *et al*., 2006). Fish feed also provides most of the nutrients required for plant growth. Aquaponics relies on the principle of the nitrogen cycle, where the dissolved waste generated from the production system is effectively converted to plant nutrients by beneficial nitrifying bacteria. Plants can utilize these nutrients for their growth (Ghaly *et al*., 2005; Nelson, 2008). Plants in hydroponics and aquaponics grow more rapidly compared to those grown in the soil because the root system is in direct contact with nutrients and nutrient uptake is more efficient (Azad *et al.*, 2013).

Currently, species of Perciformes in particular "Tilapia" are the most frequently grown fish in aquaponics (Love *et al*., 2015). More often, the Nile tilapia (*Oreochromis niloticus*) is used for aquaculture because of their rapid growth rates, good quality flesh, disease resistance, adaptability to a wide range of environmental conditions, ability to grow and reproduce in captivity and to feed at low trophic levels (REF). Since tilapia is primarily produced in intensive systems, it has become necessary to evaluate practical diets that are economically and environmentally sustainable, as well as nutritionally complete (Lim and Webster 2006).

Choosing plants that are easily adaptable to the culture medium in aquaponics systems is of great importance and the vegetables most commonly used for this purpose are lettuce, spinach, kale, basil, chard, cucumber, onion, and tomato. According to FAO (2012), tomatoes are, worldwide, the second most important vegetable crop after potatoes for aquaponics. Tomatoes are rich in nutrients, vitamins and flavonoids such as carotenoids and lycopene which are associated with a healthy diet (Higashide, 2013).

The present study was carried out to determine the ideal plant density of tomato (*Solanum lycopersicum*) in an aquaponics production system with different densities of tilapia (*Oreochromis aureus*) under UAE conditions.

Chapter 2: Literature Review

2.1 Aquaponics as a sustainable production system

Aquaponics is an integrated food production system that links recirculating aquaculture with hydroponic vegetable, flower, and/or herb production (Diver, 2006). An aquaponics system can benefit the aquaculture operation by improving the quality of recirculated water (Rakocy *et al*., 2006) or by reducing costs associated with treating effluent from flow-through raceways (Buzby *et al*., 2016). The benefits of hydroponic operation include the reduction of fertilizers inputs and labor or facilities needed to maintain adequate moisture levels. The linking of fish and plant cultures allows both operations to reduce inputs and has the potential to make the enterprise more sustainable (Tyson *et al.*, 2011).

The essential components of an aquaponics system are a fish rearing tank, a suspended solid removal component, a bio-filter, a hydroponic component, and a sump. Aquaponics is a very productive and ecologically sound food production system, where nutrients generated by the fish, either by direct excretion or microbial breakdown of organic wastes, are absorbed by plants cultured in water. As the aquaculture effluent flows through the hydroponics component of the recirculating system fish waste metabolites are removed by nitrification and directly uptaken by plants and allows the treated water to flow back to the fish rearing component for reuse (Endut *et al*., 2009).

One of the main technical obstacles to expanding aquaponics production is the difficulty of creating a system that offers optimal growth environments for fish, nitrifying bacteria, and plants in terms of temperature and pH (Tyson *et al*., 2011).

Integrating fish farming with plants has been tested in hydroponic systems where the effluent was used as a nutrient solution. These systems were designed for lettuce, tomatoes and other crops (Rakocy *et al.*, 2006 and Ghaly and Snow, 2008). Previous studies showed that different types of hydroponic systems that have been used for growing crops in aquaponics systems (Rakocy *et al.*, 2006 and Ghaly and Snow, 2008). In hydroponic plants can efficiently absorb the dissolved compounds in the wastewater as nutrients for growth (Adler *et al.*, 2003). However, the physical and chemical properties of the effluent (temperature, nutrient concentration, etc.) are dependent on the type and quality of fish being grown and may not be suitable for all crops (Buzby *et al.*, 2016).

2.2 Plant uptake and fish output

Plants require many essential nutrient elements without which they are unable to complete a normal life cycle (Bittsanszky *et al.*, 2016). In contrast to plants, fish nutrition is very different. Typically, fish feed contains an energy source (carbohydrates and/or lipids), essential amino acids, vitamins, and 21 different macro- and micro-minerals (Davis, 2015). The major source of nitrogen are the proteins used in fish cultivation and represents 50 to 70% of fish production costs (Valente *et al.*, 2011). Only 30% of the nitrogen added through feed is removed through fish harvest in intensive fish farming (Brune *et al.*, 2003) while the remaining dissolved nitrogen is released in the environment. It is estimated that between 30 and 65% of feed N is in form of ammonia and up to 40% of feed P is excreted into the surrounding environment (Schneider *et al.*, 2005). Buzby and Lin (2014) reported nitrate and phosphate removal from aquaculture effluent by

Nasturtium reduced the concentration from 0.30 to 0.11 mg L^{-1} and from 0.14 to 0.05 mg L^{-1}, respectively. Lettuce was ineffective in removing N and P.

Endut *et al*. (2016) studied an aquaponics system using the African catfish (*Clarias gariepinus*) and water spinach and mustard greens and has shown that using crop vegetables can be one of the ways to mitigate the toxic effect of ammonia. He observed significant decrease s in nitrite-N, nitrate-N and orthophosphate in aquaculture effluent. Ghaly *et al*. (2005) investigated the use of hydroponically grown barley for treatment of wastewater from recirculating aquaculture system stocked with tilapia and reported NO_2-N reductions of 98.1% after 21 days of growth. Adler *et al*. (2000) reported on the removal of P from an aquaculture effluent with hydroponic production of lettuce and basil using Nutrient Film Technique (NFT).

Aquaculture effluent can provide most of the nutrients required by plants if the optimum ratio between daily feed input and plant growing area is maintained (Rakocy *et al.,* 2004). Factors that regulate plant nutrient uptake include light intensity, root zone temperature, air temperature, nutrient availability, growth stage and growth rate (Buzby and Lin, 2014). As plants grow and biomass increases, nutrient removal from the effluent stream will improve. Therefore, to be most effective, the aquaponics system must have the correct size with the optimum balance between nutrient production from fish culture and nutrient uptake by the plant component (Buzby and Lin, 2014). Waste generation by fish is directly related to the quantity and quality of feed applied (Lam *et al.,* 2015).

When the system is in equilibrium higher stocking densities can be used to produce a higher yield of fish and plants without the use of chemical fertilizers, herbicides, or pesticides (Nelson, 2008). Diver (2006) and Rakocy *et al*. (2006) reported that with appropriate fish stocking rates the levels of NO_3, P, B, and Cu in aquaculture effluents are sufficient for good plant growth, while levels of K, Ca, and Fe are generally insufficient for maximum plant growth. The question thus arises whether it is necessary and effective to add nutrients to aquaponic systems. In such cases, Hydro Buddy is available as free software (Fernandez, 2016) to calculate the amount of required mineral nutrient supplements.

Bittsanszky *et al*. (2016) suggested that supplying the aquaponics system with additional organic nutrients, instead of mineral, could have a positive effect on both plants and the microbial population. Special care has to be taken through continuous monitoring of the chemical composition of the recirculating water for adequate concentrations and ratios of nutrients and of the potentially toxic component, ammonium. However, a perfect formulation of nutritional requirements for a particular crop does not exist, as the nutritional requirements might vary with variety, life cycle stage, day length, and weather conditions (Bittsanszky *et al*. 2016).

2.2.1 Macro and micro elements required for plant growth

For instance, nitrogen is an essential component of nucleic acids, proteins, chlorophyll, and various plant hormones (Solomon 2011). However, because plants must absorb the element in the form of fixed nitrogen, it is the most commonly deficient component in soil. Nitrogen deficiency in plants can result in stunted growth as well as yellowing and drying of the lower leaves (Kosinski 2015). Phosphorus is another macronutrient in soil. In plants, it plays a role in energy metabolism and is a fundamental element in nucleic acids, coenzymes, and phospholipids. If a plant is deficient of this essential mineral, resulting symptoms may include purple-tinted, narrowed leaves, and inhibited growth (Helms 1998). The tomato leaves appear dark in phosphorus-deficient treatments because chlorophyll synthesis is not inhibited but leaf growth is (Kosinski 2015). A study on the effect of potassium on the quality of tomato has been carried out in Khorasan (a province in Iran). The results indicated that potassium use improved the fruit yield, which led to water use efficiency (Sharayei *et al.,* 2006). The effect of potassium nutrition by irrigation on quality and fruit yield of tomato was investigated and the results indicated that the increase in potassium affected the concentration of dissolved solids (Hartz *et al.,* 2005). Eskandarpour *et al.* (2011) observed that the increase in the levels of Potasium in plant led to an increase in fruit weight and fruit quality.

The effect of increase the concentration of calcium on tomato quality in each category will lead to less fruit corruption and as a result extreme fruit time will increase significantly. According to the study Calcium as fertilizer, increased tomato resistance during the maintanence process and trasportation (Aminpour *et al.*, 2006). Calcium bonds also have an average appectate blades are necessary for wall and plant tissue destruction is destroyed by Polygalacturonase. However, once there is sufficient calcium intake, the destruction ceased (Malakouti and Rezaie, 2001). Zinc, in the probability 5% level, had a significant impact on fruit yield. The effect of soluble fertilizers on tomatoes check that these fertilizers are observed significant increase in fruit productivity and number of branches fruit rate, average fruit weight, length, as well diameter and firmness (Chaurasia *et al*., 2005). In the fruit Vegetables (citrus, bananas, tomatoes, potatoes, onions, and Therefore, an adequate amount of potassium improves its size, Color, taste and peeling property (Havlin *et al.,* 2013).

Sharma (2002) showed increasing levels of potassium in plant always increase the weight of fruit and fruit quality.

2.2.2 N flow in aquaponics systems

In aquaponics, nutrient-rich effluent from fish tanks is used to fertigate hydroponic production beds. This is good for the fish because plant roots and rhizobacteria remove nutrients from the water. These nutrients generated from fish manure, algae, and decomposing fish feed are contaminants that would otherwise build up to toxic levels in the fish tanks, but instead serve as liquid fertilizer to hydroponically grown plants. In turn, the hydroponic beds function as a biofilter stripping off ammonia, nitrates, nitrites, and phosphorus so the freshly cleansed water can then be recirculated back into the fish tanks. The nitrifying bacteria living in the gravel and plant roots play a critical role in nutrient cycling (Edwards, 2003, Diver 2006, Rakocy *et al*., 2004).

The nutrient solution needs to be prepared measured, mixed, and then added to the reservoir. In aquaponic, there's no mixing fertilizer involved, making it a great way for beginners to cultivate plants. Only the fish needs to be fed. In closed recirculation systems with very little daily water exchange (less than 2%); dissolved nutrients accumulate in concentrations similar to those in hydroponic nutrient solutions. Dissolved nitrogen, in particular, can occur at very high levels in recirculation systems. Fish excrete waste nitrogen, in the form of ammonia, directly into the water through their gills. Bacteria convert ammonia to nitrite and then to nitrate Ammonia and nitrite are toxic to fish, but nitrate is relatively harmless and is the preferred form of nitrogen for growing higher plants such as fruiting vegetables (Edwards, 2003, Diver 2006, Rakocy *et al*., 2004, 2006).

2.3 The challenge of finding an optimal nutrient balance in aquaponics systems

The balance between nutrient input and nutrient uptake is a key element in the success of aquaponic systems. If the number of fish is increased without increasing the number of plants, the nutrient production will increase while the nutrient removal will stay the same. This will result in a buildup of ammonia, nitrite and other minerals ultimately leading to fish mortalities and shutting down of nutrient production. The reason behind the increased nitrogen concentrations is that *Nitrosomonas* sp. and *Nitrobacter* sp. are unable to increase their population numbers enough to convert the excess ammonia into nitrites and nitrates (Tyson, 2007). Other nutrients will also accumulate. Nutrient deficiencies will develop quickly if the number of plants are increased without increasing the number of fish due to insufficient nutrient production. Nutrient deficiencies often lead to low quality plants that are harder to sell.

Fish feed is the main nutrient source for plants grown in aquaponic systems. Uneaten fish feed and fish waste that would be regarded as contaminants and toxins in traditional aquaculture, are transformed into high quality, liquid plant fertilizer by bacterial activity. The nutrients enter the aquaponic system water as fish feed. Fish respiration and break down of fish feed and feces produce highly toxic ammonia. About 10% of the protein content in the fish feed is transformed into ammonia (NH_3) that then dissolves and forms ammonium (NH_4^+) in water following this equation (Taiz & Zeiger, 2010):

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

Ammonia concentration is second only to oxygen concentration in importance when it comes to water quality factors affecting fish health (Tyson *et al.*, 2011). Ammonia is toxic to both plants and animals because high concentrations will reduce the activity of photosynthetic and respiratory electron transport. High concentrations of nitrate, although less toxic than ammonium, can lead to a condition called methemoglobinemia in which nitrate is reduced to nitrite that inhibits the ability of hemoglobin to bind oxygen (Taiz & Zeiger, 2010). Traditional recirculating of aquaculture facilities remove excess toxins from their system mechanically and biologically at great costs. Aquaponic systems share this waste treatment (excess toxins from their system mechanically and biologically), but the costs are reduced because the biological filters operate at a higher efficiency (Rakocy *et al.*, 2006). This is due to better conditions for biological nitrification, a process in which ammonia oxidizing bacteria of the genus *Nitrosomonas* sp. transform ammonia into nitrite (NO_2^-) while *Nitrobacter* sp. transform nitrite into nitrate (NO_3^-).

DWC (Deep Water Culture) systems provide plenty of surface area for nitrifying bacteria underneath rafts and on all surfaces within the plant tanks. This means that the aqua-cultural bio-filters can be replaced or reduced because of plant tanks in aquaponic systems supplementing these biofilters. The optimal temperature and pH ranges for maximum nitrification rates are 25–30 °C and pH 7.0–9.0, respectively. Plants remove nitrogen both as ammonium and nitrate (Taiz & Zeiger, 2010). While ammonium usually is transformed into amino acids right after assimilation, nitrate has to be reduced to nitrite and then into ammonium before being transformed into amino acids. The uptake of both ammonium and nitrate is beneficial for plant growth because the two nitrogen forms help to maintain a healthy cation-anion balance within plant tissues. Nitrogen is one of the most important nutrients for plant growth (Taiz & Zeiger, 2010).

Aquaponic nutrient solutions are often poorer than hydroponic ones which sometimes lead to nutrient deficiencies and render whole crops unsalable. Some nutrient deficiencies can, however, be negated by foliar application of a suspected deficient nutrient (Roosta & Hamidpour, 2013). Foliar application of potassium (K), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) increased the nutrient content of tomato leaves grown in an aquaponic system, but there was no change in nutrient content of the tomato fruits (Roosta and Hamidpour, 2011). Nutrient concentrations will increase, decrease, or remain constant over time if nutrient production by fish is greater than, less than, or equal to nutrient assimilation by plants and nutrient losses, respectively (Seawright *et al.*, 1997). Seawright *et al.* (1997) also suggested that optimal nutrient concentrations can be maintained through continuous monitoring and supplementation of elements that cause deficiencies. There is a challenge in keeping the nutrient concentrations within levels that lead to optimal plant growth conditions. The nutrient content of the aquaponic system depends on the nutritional content of the fish feed. Seawright *et al*. (1997) suggested that it is theoretically possible to a construct fish feed regime that can satisfy both the nutritional requirements of fish and plants without nutrient build up. Finding this optimal feed content would reduce or completely remove the need for nutrient supplements in aquaponic food production. The study of Seawright *et al.* (1997) showed that it is possible to manipulate the nutrient concentrations of K, Mg, Mn, phosphorous (P), sodium (Na) and Zn through fish feed composition, while Fe and Cu concentrations remained unchanged. Nutrient accumulation may also become problematic and even toxic. A total dissolved solids (TDS) concentration of above 2,000 ppm or 3.5 mmho/cm in electrical conductivity (EC) leads to phytotoxic (inhibitory or toxic to plants) conditions (Rakocy *et al*., 2006). Research done by Sace & Fitzsimmons (2013) showed that Chinese cabbage requires a TDS level of 1750-2100 ppm for optimal growth. Too many dissolved salts in the water can dehydrate aquatic organisms while too few dissolved salts can limit the growth of aquatic organisms where dissolved salts act as a nutrient to the organisms (Sánchez, 2014). Masri *et al.* (2016) resulted that the values of EC levels for all treatments were in a range of preference value for tilapia (0.25 - 0.75 mS/cm), also resulted that there was a relationship between TDS and salinity in the water, when the TDS concentration increases, the salinity content also increases and vice versa. This shows that plant species have different needs and tolerances of TDS levels. Zn can reach concentrations four to sixteen times higher in aquaponic systems than hydroponic systems and can lead to Zn poisoning in fish.

2.4 Factors affecting growth and development of plants

The definition of plant growth is “an irreversible increase in volume” (Taiz & Zeiger, 2010). Classical plant growth analytics has focused on measuring the size (mass) or cell number of plants, but growth can also be measured by changes in fresh weight or dry weight. Growth curves can be used to describe the change in size, weight or dry weight over a certain time period. Plant growth depends both on genetic and environmental factors (Bævre & Gislerød, 1999). Cultivars of the same species can look completely different and produce vastly different yields. Environmental factors affecting plant growth are CO_2, light and day length, temperature, relative humidity, pH and nutrient availability.

It is possible to achieve a higher degree of control of these environmental factors when producing plants inside a greenhouse where manipulation of growth factors is a requirement of modern plant production (Bazzaz & Sombroek, 1996). If the light intensity inside a greenhouse increase, the temperature will also increase leading to increased CO_2 demand by the plants. The end result will be lower CO_2 levels and an increase in plant growth. Adding CO_2 in greenhouses will result in higher or lower growth rates, yields, water use and biological nitrogen fixation depending on the plant species. Greenhouses with aquaponic systems will have increased CO_2 concentrations compared to hydroponic greenhouses without CO_2 enrichment because of fish respiration. Adding CO_2 is a common practice in greenhouse production of lettuce and fruiting vegetables because it may increase yields by up to 30 % (Becker & Kläring, 2015). Aquaponics food production might reduce the need of CO_2 addition while still producing similar lettuce yields, thus increasing the economic viability of greenhouse production (Becker & Kläring, 2015).

Optimal light levels are vital for plant growth and together with CO_2 and water provide the building blocks of photosynthesis from which plants get all their energy (Taiz & Zeiger, 2010). The maximum photosynthetic assimilation differs between sun plants that adapted to open-field light conditions and shade plants that are adapted to living underneath other plants. These plant types have evolved different light harvesting mechanisms that suit their habitats. Shade plants can be damaged by light stress if they receive light intensities of 180-250 $\mu mol/m^2/s$ that are well suited to sun plants. Sun plants may react with reduced growth if they are grown in shade plant light intensities (Taiz & Zeiger, 2010). The day length also influences growth and development rates of certain plants, especially if they are day length sensitive. Short day plants require longer periods of dark while long day plants require shorter periods of dark for inducing flowering. (Taiz & Zeiger, 2010)

Changes in temperature will affect plants in many different ways. Plant respiration, biomass increase, development phases as well as reproductive processes are all closely linked to temperature and temperature changes (Bazzaz & Sombroek, 1996). Cucumber (*Cucumis sativus*) plants produce more flowers at lower temperatures than at higher temperatures. The short day plant poinsettia delays flowering when grown in a higher night than day temperature, known as negative difference (Myster & Moe, 1995).

Petunia plants respond with longer elongation when grown in higher daytime temperatures than nighttime temperatures, and respond with shorter elongation when grown in lower daytime temperatures than night time temperatures (Kaczperski *et al.*, 1991). They found that the difference was larger at a lower light intensity, suggesting that both temperature and light intensity affect plant growth. The temperature of the root zone affects the uptake of water, nutrients and the development of the roots. The uptake rate of P and Fe decreases in lower root zone temperatures (Taiz & Zeiger, 2010). Higher temperatures lead to higher growth rates up to an optimum temperature, as the activity of all biological processes increase with increasing temperatures. The relative humidity affects the vapor pressure gradient between the air outside and inside the leaves. Low relative humidity leads to a large pressure gradient that increases transpiration water loss and vice versa.

A healthy nutrient balance is essential for successful food production regardless of production system. The nutritional needs of plants are different depending on their developmental stage. Germinating seedlings get their nutrients from the seed, while seedlings assimilate nutrients from their surroundings. Vegetative and generative growth also requires different levels of nutrients (Taiz & Zeiger, 2010). Recirculation of a hydroponic nutrient solution eventually leads to unbalanced nutrient concentrations due to many factors, including the fact that plants have a stronger affinity for certain nutrients than others and that an increase in pH leads to precipitation of minerals. An example of this is iron which is added in chelated forms such as sodium ferric diethylenetriaminepentaacetate (NaFeDTPA) in order to minimize precipitation in alkaline conditions thus keeping it available to plants. Na can become toxic to plants if the concentration gets too high in the presence of chloride (Cl) (Rakocy *et al.,* 2006). Na concentrations higher than 50 mg/L will interfere with the plant uptake of K and Ca and may lead to higher concentrations of Na and nutrient deficiencies of K and Ca within plant tissues. Increased K concentrations will affect the uptake of Mg and Ca while each of the two other nutrients will have the same effect on K uptake when they are in excess (Rakocy *et al.*, 2006).

Plants are dependent on essential elements in order to complete their life cycles. An essential element is, according to Epstein & Bloom (2005), defined as "one that is an intrinsic component in the structure or metabolism of a plant or whose absence causes severe abnormalities in plant growth, development, or reproduction". Essential elements are usually classified as macronutrients or micronutrients, based on their concentration within plant tissues. The composition of essential elements and the dilution of a modified Hoagland nutrient solution is traditionally used in hydroponic plant production. Hydrogen (H), carbon (C) and oxygen (O) are not included because these essential elements are obtained from water or carbon dioxide.

2.5 Fish rearing

2.5.1 Fish selection

The type of fish used in an aquaponic system depends on the climate which will surround the aquaponic system and therefore the temperature the grower is able to maintain, the kinds of fish that the local fisheries department has specified as legal (there are sometimes restrictions on the cultivation of fish that are not native to the region), the type of fish desirable for consumption by consumers and the type of fish feed available to the grower (Nelson, 2008**).**

Most commercial systems, however, culture tilapia. Tilapia is one of the most popular fish species in aquaponics systems (Rakocy *et al.*, 2006) and the basic requirements for successful biological processes in aquaponic systems (Love *et al.*, 2014). Tilapia has a great attraction 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). Due to these characteristics, tilapia culture is being practiced in most of the tropical, subtropical and temperate regions to meet the global rising demands for proteins (Ng & Romano, 2013). Fish produce ammonia which is the major end product in the breakdown of proteins. Ammonia is converted to nitrate by bacteria (Rakocy *et al.*, 2006).

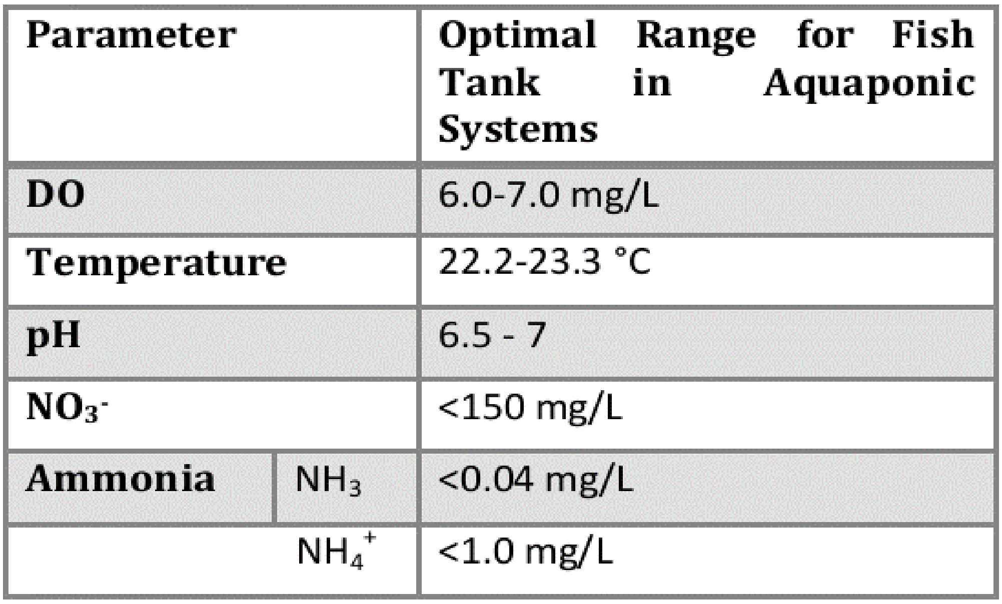
2.5.2 Culturing conditions for tilapia

Although very dependable and resilient to changing conditions, tilapia – like all other fish species – have certain conditions at which they grow best.

2.5.2.1 Water quality

Good water quality must be maintained at all times in a recirculating fish tank to maintain optimal growth conditions and health of the fish. Regular water quality testing is essential and can be performed using water quality testing kits obtained from aqua-cultural supply companies. The most critical water quality parameters to monitor are dissolved oxygen concentrations, temperature, pH, and nitrogen from ammonia, nitrate and nitrite. Nitrogen in the form of nitrate and nitrite usually does not present a water quality problem in aquaponic fish tanks as nitrite is quickly converted to nitrate and nitrate itself is only toxic to fish at very high levels (300-400 mg/L). The biofiltration mechanism in aquaponic systems also removes nitrates quite well and can maintain their concentration at much lower levels (DeLong *et al.*, 2009). Thus the most important water quality parameters are temperature, dissolved oxygen and ammonia. Other important parameters include salinity, phosphate, chlorine and carbon dioxide. Other factors that influence the quality of fish tank water include the stocking density of the fish, their growth rate, the rate at which they are fed, the volume of water in the system and environmental conditions (Diver, 2006). The ideal values of water quality parameters for tilapia aquaponic systems are summarized in Table 1.

Table 1: Summary of ideal water quality condition for an aquaponic fish tank for tilapia (Raghavan, 2010)



Parameter		**Optimal Range for Fish Tank in Aquaponic Systems**
DO		6.0-7.0 mg/L
Temperature		22.2-23.3 °C
pH		6.5 - 7
NO_3^-		<150 mg/L
Ammonia	NH_3	<0.04 mg/L
	NH_4^+	<1.0 mg/L

2.5.2.1.1 Dissolved Oxygen (DO)

Tilapia can survive acute exposures to DO levels as low as 0.5 mg/L, but they prefer a range of 3-10 mg/L (Nelson, 2008), with ideal growth occurring at levels higher than 5.0 mg/L (DeLong *et al*., 2009). For aquaponic systems in general, a DO level of 80% saturation (6-7 mg/L) is optimal.

2.5.2.1.2 Temperature effects

Different tilapia species have different temperature range requirements for optimal growth. None of the species can survive under 10 °C (Nelson, 2008). They do well in a range of 17-32 °C, depending on the species but ideal growth occurs at 26.7 °C and higher (DeLong *et al*., 2009). In aquaponics, tilapia are usually raised between 22.2 and 23.3 °C in order that the needs of the fish, the nitrifying bacteria and the aquaponic plants are met as plants perform better at slightly lower temperatures (Nelson, 2008).

These slightly lower temperatures also allow for a higher dissolved oxygen content as the solubility of oxygen in water decreases with increasing temperature (DeLong *et al*., 2009).

2.5.2.1.3 Influence of pH

Most fish grow best at a pH of 7.5-8.0. Tilapia can tolerate a large pH range (from 5 to 10), with ideal functioning occurring between pH 6 and 9. In a recirculating aquaculture system that involves filtration through a biofilter (such as a hydroponic, media-filled grow bed), the pH of the fish tank water must agree with the pH suitable for the survival of the nitrifying bacteria growing in the biofilter. Plants in aquaponic systems do best at pH 6.0-6.5 and the nitrifying bacteria perform best at pH 6.8-9.0. Thus, a degree of compromise must be made to satisfy all three systems. Often in aquaponic systems a water pH of 6.5 to 7 is maintained (Nelson, 2008).

2.5.2.1.4 Ammonia influence on aquaculture system

Ammonia is a product of the fish waste and can be highly toxic to fish when it accumulates in their culture water. The unionized form of ammonia (NH_3) is highly toxic to fish and other aquatic life, while the ammonium ion (NH_4^+) is much less (DeLong *et al*., 2009).

In the aquaponic system with a pH of 7, the most of the ammonia is in the ammonium ion form. High pH values increase the proportion of ammonia that is in the toxic unionized ammonia form (Droste, 1996). Regular exposure to NH_3 concentrations exceeding 1 mg/L will lead to gill disease and fish will begin to die at levels as low as 0.2 mg/L, with other functions ceasing to operate at even lower values (Popma & Masser, 1999). Thus, one should strive for a concentration of NH_3 that is as close to zero as possible in aquaculture systems (Graber & Junge, 2009). Tilapia can maintain their health at an ammonia concentration range of 0.00-0.04 mg/L (Nelson, 2008). Concentrations of the ionized form of ammonia should be maintained below 1 mg/L NH_4^+ (Graber & Junge, 2009).

2.5.2.2 Feeds of fish

Tilapia are largely omnivores and respond well to commercial fish feed. Their diets need to be well balanced in terms of amino acids, proteins, fats, vitamins, minerals and carbohydrates (Riche & Garling, 2003). Expertly formulated feeds that provide all of these components for tilapia are quite common. In natural environments, wild tilapia may feed on algae (low in protein) and small animals such as worms (high in protein). Small-scale aquaponic growers may choose to feed their fish with a mixture of these materials; however optimum tilapia growth is obtained by using commercial feed pellets. Fish in culture require less food than wild fish as they need less energy to survive and obtain food and thus the controlled use of fish feed pellets gives the grower complete control of the nutrient inputs into the aquaponic system (Riche & Garling, 2003).

In aquaponic systems, tilapia grow best when fed three times daily *ad libitum* (the amount of food that they will eat in 30 minutes) (Rakocy *et al*., 2004), where the feed is composed of 32% protein (Spade, 2009). Determining the amounts of fish feed per tank per day over the growing period of the tilapia based on average fish weight is considered an over-complication by aquaponics experts. Instead, empirical values have been established for the amount of daily fish feed per area of hydroponic grow bed. This allows for the calculation of the number of fish the system can grow and consequently the volume of water needed to stock the fish. Overfeeding fish will result in uneaten food (will compromise water quality), lower feed efficiency, reduced health of fish and increased costs (Riche & Garling, 2003).

2.6 Bacteria in aquaponics

Bacteria are one of the three basic requirements to complete the biological processes (nitrification) in aquaponics system. Nitrification is a major biological process in bio-filter aquaponics and forms the basic process for removing ammonia, a metabolic waste excreted by fish. Ammonia is toxic to fish at concentrations above 0.05 mg L^{-1} (Rakocy *et al.*, 2006). Nitrification in aquaponics provides elements for the plants which eliminates ammonia and nitrite (Gutierrez-Wing & Malone, 2006) through two types of bacteria. The first type is composed of *Nitrobacter*, *Nitrospina* and *Nitrococcus*, a group of nitrifying bacteria that oxidize ammonia (NH_3 or NH_4^+) into nitrite (NO_2^-) which is also toxic to fish. The second type of nitrifying bacteria composed of *Nitrosomonas* and *Nitrosococcus* that oxidize nitrite and converts it into nitrate (NO3-) (Somerville *et al*., 2014). In aquaponics, biofilters use sand, gravel, shells or various plastic media with large surface areas which is optimal to develop extensive colonies of nitrifying bacteria (Rakocy *et al.*, 2006). The nitrification process results in the transformation of 93% to 96% of ammonia-nitrogen to nitrate, an end product of nitrification, in infiltration units (Prinsloo *et al*., 1999). Nitrate is the primary source of nitrogen for plants (Resh, 2012). Nitrite is the intermediate product of nitrification and toxic to both fish as well as plants while nitrate is not toxic to fish. The nitrifying bacteria in aquaponics systems are affected by pH. The optimum pH range for nitrification is 7.0 to 9.0 although most studies indicate that the ideal pH for efficient activity of *Nitrosomonas* spp. is 7.8 to 8.0 and for

Nitrobacter spp. it is 7.2–8.2. On the other hand, the optimal temperature range for nitrifying bacteria is 17 to 34 °C while the optimum levels of DO for the nitrification process is 4 to 8 mg L^{-1}. (Somerville *et al*., 2014**)** This is the level required for both fish and plants. Nitrification is affected negatively if DO level is less than 2 mg L^{-1}. It is mandatory to ensure adequate pH, water temperature and DO for successful bio filtration process (Rakocy *et al*., 2006).

2.7 Plant and fish in aquaponic system

Two tomato cultivars were planted (Geronimo and Blitz) as transplants in October at a total of 600 plants in the 30 x 96 foot house. Fertilizers were applied pre-plant and subsequently on an as needed basis. Irrigation was provided both from a nearby rain-filled reservoir and water being removed from the fish house as water was exchanged as described by Jchappell *et al*. (2008) showed that aquaponics can produce 10 to 12 tons of Tilapia per cycle annually equating to 350 - 400,000 pounds per acre per year. Tomato production was similarly robust at about 10,000 pounds per cycle. Two cycles per year would normally be cultured so about 10-12 tons per greenhouse of this size per year. This computes to 300-360,000 pounds of tomatoes per acre per year.

Graber and Junge (2009) indicated that the highest nutrient removal rates by fruit harvest were achieved during tomato culture: over a period of >3 months, fruit production removed 0.52, 0.11 and 0.8 g $m^{-1}d^{-1}$ of N, P and K in hydroponics and 0.43, 0.07 and 0.4 g $m^{-1}d^{-1}$ of N, P and K in aquaponics, respectively. In aquaponics, 69% of nitrogen removal by the overall system could thus be converted into edible fruits. Plant yield in aquaponics was similar to conventional hydroponic production systems.

Roosta and Hamidpour (2011) showed that biomass gains of tomatoes were higher in hydroponics as compared to aquaponics. Foliar application of K, Mg, Fe, Mn, and B increased the vegetative growth of plants in aquaponics. In hydroponics, only Fe and B had positive effects on plant growth. Cluster number per plant in aquaponics was lower than in hydroponics treatments, but it increased with foliar application of elements (Fe and B). There was no difference in fruit number and yield between aquaponics and hydroponics grown plants in the control treatments. Except for Cu, foliar spray of all elements significantly increased plant fruit number and yield in the aquaponics in order of: K > Fe > Mn > Zn > Mg > B. In hydroponics, foliar application of K, Mg and Zn increased fruit number and yield of plants compared to the control. These results indicated that foliar application of some elements can effectively alleviate nutrient deficiencies in tomatoes grown in aquaponics.

Roosta and Mohsenian (2012) investigated the effects of foliar applications of different Fe sources on pepper plants grown in alkaline aquaponic solutions. The results showed that the overall growth was significantly increased by foliar Fe application, and the highest values of vegetative and reproductive growth parameters were recorded in plants treated with $FeSO_4$. The lowest chlorophyll content was observed in untreated plants. The highest SPAD index, maximal quantum yield of PSII photochemistry (Fv/Fm) and performance index (PI) values of young and old leaves were found with $FeSO_4$. There were no difference between Fe-EDTA and Fe-EDDHA treatments. The Fe treatment led to a significant increase of shoot Fe concentration in pepper plants. The highest shoot Fe concentration was observed in plants sprayed with Fe-sulfate, whereas Fe-EDTA and Fe-EDDHA led to intermediate concentrations and the control had the lowest concentration. Foliar fertilization of pepper plants with different Fe sources had a beneficial effect on the essential nutrient uptake and transport in plants. The results revealed that an application of foliar Fe must be practiced for aquaponic systems to overcome Fe deficiencies in alkaline conditions and to improve the nutritional status of pepper plants.

Using the effluent fish farm could save fertilizers with equivalents of 0.13 LE kg^{-1} fruits (130 LE t^{-1} fruits) which mean 130 pound for ton of fruit. Khater *et al.* (2015) indicated that the nutrient consumption increased with increasing the flow rate. The root and shoot length of tomato plant increased with increasing effluent flow rate, when the effluent flow rate increased from 4.0 to 6.0 L h^{-1}, the length of the roots and shoots increased from 50.33 to 55.33 and 149.33 to 191.33 cm, respectively, at the end of growing period. The fresh and dry mass of the shoots significantly increased from 998.01 to 1372.10 and 83.71 to 275.09 g plant^{-1}, respectively, by increasing the flow rate from 4.0 to 6.0 L h^{-1}. The fresh and dry mass of the roots increased from 388.07 to 423.91 and 30.37 to 38.98 g plant^{-1}, respectively, when the flow rate was increased from 4.0 to 6.0 L h^{-1}. The fruit yield increased from 1.06 to 1.37 kg plant^{-1} by increasing flow rate from 4.0 to 6.0 L h^{-1}. The fruit mass and number of fruits increased from 75.07 to 81.32 g and 14.12 to 16.85 by increasing the flow rate from 4.0 to 6.0 L h^{-1}. The water use efficiency increased from 5.54 to 7.16 kg m^{-3} by increasing the flow rate from 4.0 to 6.0 L h^{-1}.

Component ratio (hydroponic tank volume to rearing tank volume) on the fish growth, vegetable yield, and nutrient removal was investigated by Lam *et al.* (2015). Increased fish growth (2.4 g/day), vegetable yield (22 kg/harvest), and nutrient removal (83% ammonia-N removal, 87% nitrite-N removal, 70% nitrate-N removal, 60% removal of total phosphorus, 88% removal of total suspended solid, 63% removal of 5- day bio chemical oxygen demand) were observed at high component ratio (3 m^3/m^3). Component ratio was found to have a influence on nutrient removal and production of marble goby and water spinach in RAS (recirculating aquaponic system). A component ratio of ≥ 3m^3 of hydroponic tank volume to 1 m^3 of fish rearing tank volume showed advantages in improving the production of the fish and vegetable and removing the nutrient wastes, TSS (total suspended solid), and BOD_5 (biochemical oxygen demand) generated from the culture of the fish. The results indicated that RAS show exceptional promise as a means for the reduction of biological nutrients accumulated in aquaculture wastewater and in turn providing a good water quality environment for fish culture.

Saufie *et al*. (2015) evaluated the growth performances of genetically improved farmed Tilapia (GIFT) and tomato plant (*Solanum lycopersicum*) in a combined aquaponic system. The result indicated that GIFT gained 94% of body weight and tomato increased by 96.3% in terms of plant height. The plants also started flowering early (the early stage of fruit formation). In addition, the range in concentration of TAN (total ammonium nitrogen) (0.29±0.4 mg LG^1), nitrite (0.65±0.59 mg LG^1), nitrate (1.29±1.29 mg LG^1) and phosphate (0.57±0.1 mg LG^1) in the culture system were suitable for facilitating the nitrification process. The analysis of the data proved that the combined aquaponic system is more effective than the single DWRS (Deep Water Raft System) aquaponic system.

Suhl *et al*. (2016) demonstrated that in double recirculating aquaponic systems (DRAPS) comparable tomato yields were produced as obtained for conventional hydroponics. Even fruit parameters such as content of lycopene and ß-carotene resulted were the same when both systems were compared. Furthermore, the fertilizer use efficiency was increased by 23.6% in favour of the DRAPS. The total fresh water use efficiency was also increased using aquaponics.

The effect of juvenile Nile tilapia (*Oreochromis niloticus*) (in unit I) and Common carp (*Cyprinus carpio*) (in unit II) on plant growth (cucumber, tomato and lettuce) was investigated by Knaus and Palm (2017) in two identical gravel substrate ebb-and- flood coupled aquaponic units (I, II) with 3.81 m^3 total water volume and without addition of fertilization for 70 days. The tomato gross biomass was two times higher in combination with *O. niloticus* and tomato fruit weight was slightly higher. The growth of cucumber showed higher total fresh biomass in the *C. carpio* unit. Lettuce yield was near zero as a result of inter-specific competition (in which units) The Aquaponics Growth Factor (AGF) describing the growth performance of fish and plant combinations, was highest in tomato (1.12) combined with *O. niloticus* compared to *C. carpio* (0.53). However, the AGF of cucumber was slightly higher in combination with *C. carpio* (0.14) compared to *O. niloticus* (0.12). This study demonstrated that tomato grew best when combined with *O. niloticus* whereas cucumber performed best with *C. carpio.*

Yıldız and Bekcan (2017) studied the production of Nile tilapia (*Oreochromis aureus*) and tomato (*Solanum lycopersicum*) in a classical aquaponics system (one-loop) with different fish densities. Ninety six tilapia juveniles (*O. aureus*) were stocked at different ratios: 25 kg/m^3 (Group I), 35 kg/m^3 (Group II) and 50 kg/m^3 (Group III) and fed with 45% raw protein feed at the level of 2% body weight for 126 days. Fish density affected the fish growth parameters and the most densest group showed the best results in terms of fish growth and feed efficiency. Water quality parameters measured fluctuated during the experiment even the exceed of the optimal ranges for the fish. However, tilapia tolerated the changes of water quality. The total plant biomass was low due to various limiting factors including insufficient lighting of the in-door aquaponics system and a low level of water potassium. The results of this study clearly illustrated that fish stocking rate has an impact on total biomass in the aquaponics and in one-loop aquaponics the water quality fluctuation is the main challenging factor.

2.8 The future potential of aquaponics

Food that was earlier produced in fields has been transferred into greenhouses and buildings while the growing media has changed from soil to soilless production in hydroponic and aquaponic systems. Hydroponic plant production uses much less water compared to field grown plants that only absorb about 10 % of the irrigation water given to them. Aquaponic systems save even more water since the water does not have to be replaced at regular intervals. There is an increasing trend in which the general population demands ecological, chemical free food. Aquaponics plant and fish production is able to provide exactly this, as both fish and plants are produced in an ecological way without any chemicals in some cases.

International regulations are expected to reduce the negative environmental effects of aquaculture, especially when it comes to wastewater dumping (Blidariu & Grozea, 2011). This could place limitations on the fish production of flow-through and recirculating aquaculture facilities, even though fish farming is the fastest growing food sector in the world. Hydroponic farmers and aquaculture producers are already converting to aquaponic systems which supports the notion that aquaponic systems might provide both the salad ingredients and the meat of tomorrow (Savidov *et al.*, 2007). Challenges in achieving an optimal nutrient balance between the production and assimilation of nutrients within the aquaponic system, controlling pests with biological agents and a greater variety of both plant and fish crops should be researched further to pave the way for this environmentally friendly food production system. Cold water aquaponic systems could make the whole year production of plant crops in temperate and arctic climates possible without increasing water temperatures to suit warm water crops. This would make aquaponics more economically viable, especially when aquaponic systems are able to produce similar yields to hydroponic systems while simultaneously producing fish as a byproduct.

There are some challenges and potential problems with aquaponics. First, aquaponics and organic soil agriculture are both limited by the effectiveness of pest control. Only organic pesticides, biological and mechanical controls, such as physical barriers and traps, can be used to protect the crops from pests. The effectiveness of biological and mechanical controls depends on the weather (Turkmen, 2010). Secondly, careful operations must be taken in order to keep the aquaponic system from being contaminated by harmful bacteria, such as E. coli, which affect bring the health of the fish and crops (Hollyer *et al.*, 2009). If ground soil is used in the system, it should be sterilized by UV radiation to prevent contamination (Graber & Junge, 2009). In addition, the system must be kept away from animal manure because the manure may contain harmful bacteria. In short, aquaponic systems can reduce the amount of wasted water and nutrients, and synthetic chemicals, but may require elaborate operation and maintenance.

Chapter 3: Materials and Methods

3.1 Study area

This study was carried out in the PVC (polyvinyl chloride) greenhouse on the area reserved for experiments in the College of Food and Agriculture at Falaj Hazza campus ALA in, UAE

3.2 Materials used

In this study a small-scale aquaponics system with a grow bed form producing tilapia (*Oreochromis aureus*) and tomato (*Solanum lycopersicum*) were used as the fish and the plant materials, respectively.

3.3 Experimental set up

Treatments were arranged in complete randomize block design with 3 replicates as follows. Tilapia (*Oreochromis niloticus*) were stocked at different ratios: 100 kg/m^3 (Group I), 120 kg/m^3 (Group II) and 140 kg/m^3 (Group III). Tomato plants were sown in vegetation foam plates each with 2, 3 or 4 plantlets.

3.4 Preparation of the experiment

The aquaponics experimental system comprised of 3 fish tanks and 3 foam plates filled with hydration for vegetable beds. Each vegetation foam plate contained either 2, 3 or 4 plantlets of tomato (*S. lycopersicum*). Each fish tank was filled with 7.754 m^3 of tap water and aerated continuously with an air stone. Water loss due to sampling and evaporation was replenished with the addition of tap water until access to the quantitative under study.

Nitrifying bacteria, *Nitrosomonas europaea* and *Nitrobacter winogradskyi* were added to the system at the initial period. Experiments were run in three replicates. Normal lighting was used.

3.5 Preparation of tilapia fish tanks

The individual fish number in each green-house was 800 with total weight in green-house 1 being (9.6-15 kg), greenhouse 2 (18.10-21.65 kg) and greenhouse 3 (8.7-10.75 kg) at the beginning of the experiment (shown in Figure 1). Fish was fed 3 times/day for 7 months. The chemical composition of the feed is presented in Table 2.

Monthly added organic mineral for maintaining the water quality and tomato fruit ripening and quality.

Table 2: Chemical composition of the feed in this study

Month	**$CaCO_3$ (kg)**	**$Ca(NO_3)$ (g)**	**$MgSO_4$ (g)**	**$KHPO_4$ (g)**	**Chelated Fe (kg)**
1	2	-	-	-	-
2	2	-	-	-	1
3	2	350	350	350	-
4	2	350	350	350	1
5	1	350	350	350	-
6	1	350	350	350	1
7	1	350	350	350	-
Total	11	1750	1750	1750	3

Figure 1: Tank of nile tilapia fish

3.6 Tomato cultivation

At the same time as commencement of tilapia culture, tomato seeds were sown in the nursery in vegetation foam plates under plastic low tunnel protection on 6th of December 2016. Each plate had 2, 3 or 4 seeds and 10 foam plates were used for each treatment. The total number of plants was 20, 30 and 40 seedlings in the experiment. Germinated after 4 days from the sowing (Figure 2) and initiated flower after 35 days from sowing as shown in Figure 3. After 4 months harvest started and completed over a period of 4 months.

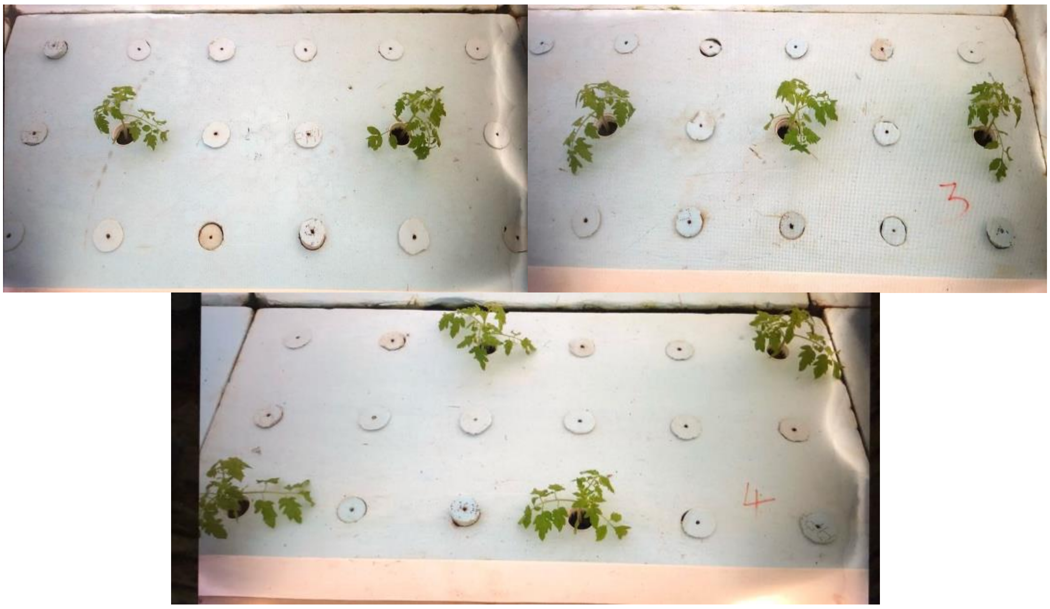


Figure 2: Tomato plants germination

Figure 3: Tomato plants flowering

3.7 Analytical procedures

After 7 months of rearing, the fish was harvested and their growth performance was measured using the parameters as shown below.

- No of fish every 2 month.
- Weight of fish (kg)
- Weight gain (kg)
- Mean W g/fish (gm)
- Consumed feed (kg)
- Feed Conversion Ratios (FCR): FCR= food intake/ weight gain.

Tomato plants were harvested after 4 months from sowing. The plants were randomly taken from each treatment and moved immediately to the laboratory. The plant growth and yield parameters were expressed as:

- No of tomatoes / plant
- Tomato yield/plant (gm)
- Average weight (gm/plant)
- Average height (mm/plant)
- Average width (mm/plant)

Representative samples of tomato fruits were randomly taken from each treatment every month to determine their quality parameters expressed as follows: Ca, Mo, Mg, Na, P, S, K, Cu, Fe, Mn and Zn. The dry matter, moisture, ash, crude protein, crud fiber and percentage fat% was measured.

3.8 Water quality measurements

Water quality parameters in the fish tanks were routinely measured every month for 8 months. During the experimental period the water temperature was kept about at 23 to 29 °C (this is a big range). Dissolved oxygen (DO), temperature (T) and pH were measured as well as TDS (total dissolved Solids) and EC (electrical conductivity). Other water quality parameters including ammonia (NH_3), Nitrate (NO_3^-), Nitrite (NO_2^-), iron (Fe), alkalinity and acidity as well as Light Intensity in aquaponic tanks were measured every 15 days by using Standard Methods (APHA, 2005). The average monthly water and electric consumption for each aquaponics unit tomato cultivation raceway, cooling system and water flow rate were determined (Table 3).

Table 3: Monthly average water and electric consumption for the three aquaponics unit/tomato cultivation raceway, cooling system and water flow rate

System	**Month**	**Total system water Volume** m^3	**Monthly water consumption** m^3	**Evaporation** m^3	**Water usage for cooling system** m^3	**Electric Usage (K.wh)**	**Water flow rate** (m^3**L/hour)**
1 (100 kg/m^3**)**	**1**	57.95	5.03	5.03	21.99	1586.8	10
	2	57.95	10.46	10.46	3.77	717.6	10
	3	57.95	29.03	29.03	2.65	1101	10
	4	57.95	12.93	12.93	18.89	1169	10
	5	57.95	14.41	14.41	103.38	1904	10
	6	57.95	34.81	34.81	65.47	1470	10
	7	57.95	15.11	15.11	182.96	3144	10
	8	57.95	7.82	7.82	52.13	830.5	10
	Total		**129.61**	**129.61**	**451.23**	**11922.9**	
2 (120 kg/m^3**)**	**1**	57.95	3.82	3.82	13.49	1476.60	10
	2	57.95	6.05	6.05	4.91	940.90	10
	3	57.95	4.16	4.16	3.73	981.30	10
	4	57.95	12.24	12.24	26.72	1190.70	10
	5	57.95	10.60	10.60	81.87	1603.50	10
	6	57.95	9.71	9.71	67.27	1559.10	10
	7	57.95	15.83	15.83	182.20	2975.00	10
	8	57.95	1.61	1.61	55.83	836.50	10
	Total		**64.02**	**64.02**	**436.01**	**11563.60**	
3 (140 kg/m^3**)**	**1**	57.95	3.69	3.69	10.14	2128.60	10
	2	57.95	5.38	5.38	3.46	883.70	10
	3	57.95	14.45	14.45	5.38	1228.60	10
	4	57.95	40.51	40.51	30.14	1599.80	10
	5	57.95	29.47	29.47	66.45	1985.00	10
	6	57.95	29.83	29.83	102.93	2290.00	10
	7	57.95	39.83	39.83	168.36	3527.00	10
	8	57.95	11.32	11.32	45.83	1533.00	10
	Total		**203.95**	**203.95**	**432.69**	**1517.7**	

3.9 Methods of samples analysis

Prior to drying the fruits were cut into halves and the dried samples were ground to a powder. To determine phosphorus (P), potassium (K), calcium (Ca), copper (Cu), sulfur (S), magnesium (Mg), manganese (Mn), zinc (Zn), molybdenum (Mo) and iron (Fe) were analyzed by an electrothermal atomic absorption spectrophotometry method for samples described by Kumpulainen *et al*. (1983).

Total ash content: Two grams of the sample were added into a previously weighed porcelain crucible and placed in a muffle furnace at 600 °C for 2 h. The samples were then placed in desiccators, cooled and weighed. The weight of the residue was calculated and expressed as percent ash (AOAC, 2000).

Crude Fat (Ether Extract): Ten grams of each powdered sample were extracted using a continuous extraction apparatus (Soxhlet) with a solvent of petroleum ether (b.p.60-80 °C) for sixteen hours. Each extract was dried over anhydrous Na_2SO_4 and evaporated to dryness. The residue was dried at $80^{O}C$ for 10 min, cooled, weighed and expressed as percent lipid (AOAC, 2000).

Crude Fiber Contents: Two grams of the defatted powder of each sample were boiled with 200 ml of 1.25% sulphuric acid under reflux for 30 min and filtered. The residue was washed with distilled water, then transferred back to the flask with 200 ml of 1.25% NaOH solution. It was boiled for 30 min under reflux, rapidly filtered and washed with distilled water. The residue was dried at 100 °C to constant weight. The difference between the weight of residue after drying at 110 °C and of the powder represents the weight of crude fiber (AOAC, 2000).

Moisture Contents: Five grams of each air-dried powder sample were accurately weighed in a porcelain crucible, then dried in an oven at 105 °C until the weight was constant. The loss in weight was calculated and reported as percent moisture (AOAC, 2000)

3.10 Statistical analysis

This experiments were conducted as a completely randomized design with three replicates. The data were analyzed by analysis of variance (ANOVA). Duncan’s multiple-range test was used to compare differences among individual means as described by Gomez and Gomez (1984**)**. Treatment effects were considered significant at $p<0.05$. All statistical analyses were performed by means of CoSTATE Computer Software.

Chapter 4: Results and Discussion

4.1 Water quality

Water quality parameters measured in the three aquaponic systems including temperature, DO, pH, TDS, EC, ammonium, nitrite, nitrate, iron, alkalinity, acidity and light intensity are presented in the Table 4. Water quality parameters except water temperature showed significant differences ($p<0.05$) with times and the experimental groups. The water temperature remained at around 20.38-29.42 °C (Table 4). Dissolved oxygen levels ranged between 4.26 mg/L (min) and 5.18 mg/L (max). The range of pH was between 6.45 and 6.79 in Group I, 6.26-6.54 in Group II and 6.30-6.67 in Group III. The TDS increased from 290.33, 3.14.00 and 331.50 ppm with increasing time up to 366.40, 716.80 and 592.80 ppm for Group I, II & III, respectively. Electrical conductivity ranged between 15.52 mV in Group I up to 42.80 mV in Group III.

Table 4 showed that ammonium levels varied between 0.10 and 1.08 mg/L in Group I, 0.24 and 1.16 mg/L in Group II and 0.16 and 1.23 mg/L in Group III. Nitrate levels were between 5.90 and 22.40 mg/L in Group I, 5.95 and 24.30 in Group II and 7.01 and 25.08 mg /L in Group III. Nitrite levels ranged from 0.09 to 0.22 mg/L in Group I, from 0.14 to 0.29 mg/L Group II and from 0.13 to 0.62 mg/L in Group III. Iron values in water ranged from 0.10 to 0.68 mg/L in Group I, from 0.09 to 0.87 mg/L in Group II and from 0.10 to 0.72 mg/L in Group III. Alkalinity during the experiment varied between 25.33 to 43.75 in Group I, 24.50 to 42.50 in Group II and 25.67 to 42.00 in Group III. Acidity ranged between 2.80 to 16.25 in Group I, 4.83 to 17.20 in Group II and 4.17 to 17.00 in Group III. Finally, light intensity (Lux) ranged between 950 to 1250 in Group I, 750 to 1500 in Group II and 763 to 2000 in Group III.

In addition, pH values fluctuated in all groups during the present study. pH is one of the crucial factors in aquaponics and should be kept around 7 for nitrification and converting ammonia and providing nitrate for the plants (Goddek *et al*., 2015; Monsees *et al*., 2017). Although the pH values were below the optimal value for the fish in this experiment the tilapia tolerated the pH changes. On the other hand, the pH values were suitable for the plants. Most plants need a pH value of between 6 and 6.5 in order to enhance the uptake of nutrients as has been shown by Goddek *et al*. (2015**)**. It is known that pH<6.5 disrupts the nitrification process with eventual risk of ammonia and nitrite toxicity. In this study, ammonia and nitrite levels were high while the pH was low. The highest ammonia and nitrite corresponded to the lowest pH values. However, in our case, the nitrate values reached higher values and this may be explained by the insufficient nitrate uptake of the plant due to weak lighting. Thus, the interaction of the water quality parameters in the aquaponics with media based growing bed is more complicated and difficult to keep within optimal ranges. In terms of optimal production parameters decoupled systems are taken into consideration, as stated by Monsees *et al.* (2017).

The EC values in Table 4 found in the present study were higher- comparing with the most adequate EC is around 2.5 to 2.6 dS m-1 (Costa *et al.,* 2001; Gondim *et al.,* 2010) as illustrated n lettuce cultivation in aquaponic system. In aquaponic systems, EC has higher values due to the lower rate of water replacement promoting greater accumulation of ions in the solution. This result was agree with those obtained by Rodrigo *et al*. (2018) found that in aquaponic system, the lower rate of water replacement and raise of a huge accumulation of ions in the solution led to higher values of EC. However, due to the supply and continuous recirculation of water the conditions become satisfactory for plant cultivation (Rakocy *et al*., 2006).

The ammonia and nitrate concentrations measured in the water used for the culture cycle did not exceed the limits proposed as safe levels. Frías-Espericueta *et al*. (1999) recommended a safe value of 6.5 mg/L for ammonia to avoid toxic effects on juveniles and Van Wyk & Scarpa (1999) and Kuhn *et al.* (2010) stated that concentrations below 60 and 220 mg/L for nitrate, respectively, had no negative effects on survival or growth. Nitrite concentrations were maintained below 0.45 mg/L which was proposed by Gross *et al.* (2004) as a safe level.

Table 4: Monthly average water quality parameters of aquaponics effluent in tanks 1 to 3

System	Months during 2016	Temperature (°C)	Dissolved Oxygen (mg/l)	pH	TDS (ppm)	EC (mV)	Ammonia (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	Fe (mg/l)	Alkalinity	Acidity	Light Intensity (Lux)
Group I (100/m^2)	**October**	23.85e±0.02	5.03b±0.03	6.79a±0.03	290.33h±1.100	15.52h±0.044	0.10e±0.03	5.90h±0.03	0.37a±0.02	0.10f±0.02	25.33f±0.10	2.80h±0.09	1100b±50
	January	21.57g±0.03	4.93cd±0.04	6.68b±0.03	369.67c±1.24	19.17g±0.04	0.21d±0.03	8.77g±0.05	0.14cde±0.04	0.14ef±0.03	35.00e±0.09	8.67e±0.06	1200a±100
	February	20.88h±0.03	5.00b±0.04	6.49ef±0.02	333.25f±0.82	19.90f±0.04	0.19d±0.03	15.58f±0.077	0.09e±0.04	0.16e±0.03	43.75a±0.06	5.00g±0.12	1029bc±76
	March	22.53f±0.02	4.88d±0.03	6.45f±0.04	388.00b±1.42	30.40b±0.02	0.18d±0.02	18.45e±0.07	0.10de±0.03	0.26d±0.03	40.25d±0.07	6.25f±0.07	1250a±40
	April	25.10d±0.03	5.18a±0.03	6.36g±0.04	439.50a±1.05	38.78a±0.03	0.65b±0.022	18.73d±0.08	0.16c±0.03	0.43c±0.02	41.25c±0.09	10.75d±0.06	900d±50
	May	28.48c±0.03	4.98bc±0.03	6.56cd±0.02	310.25g±0.73	25.00d±0.03	1.08b±0.05	22.40a±0.03	0.22b±0.02	0.59b±0.04	42.50b±1.05	16.25a±0.06	1018bc±12
	June	29.26b±0.02	4.80e±0.03	6.60c±0.05	366.40d±0.83	29.76c±0.03	0.52c±0.02	20.58c±0.07	0.15cd±0.02	0.67a±0.05	40.80cd±0.04	16.00b±0.13	1000c±50
	July	29.35a±0.03	5.00b±0.05	6.53de±0.03	340.50e±0.94	24.15e±0.02	0.62b±0.03	21.55b±0.09	0.19bc±0.03	0.68a±0.03	42.50b±0.03	15.50c±0.07	950cd±30
Group II (120/m^2)	**October**	24.05e±0.06	5.07ab±0.05	6.54a±0.03	314.00g±0.58	29.98g±0.05	0.26ef±0.02	5.95h±0.06	0.35a±0.03	0.09g±0.03	24.50h±0.07	4.83g±0.05	750e±50
	January	21.50g±0.03	5.13a±0.03	6.26d±0.04	422.67f±0.75	41.17b±0.05	0.24f±0.03	15.67g±0.06	0.29ab±0.05	0.20f±0.05	30.00g±0.11	9.33e±0.05	825de±65
	February	20.38h±0.03	5.03bc±0.04	6.39b±0.03	448.75e±0.59	29.50h±0.04	0.28ef±0.03	20.08e±0.08	0.17de±0.02	0.21f±0.02	34.25f±0.08	7.00f±0.12	900d±30
	March	22.33f±0.02	4.93d±0.05	6.40b±0.03	497.50d±0.97	30.78f±0.02	0.30e±0.02	22.18d±0.05	0.14e±0.02	0.33e±0.04	40.50c±0.07	7.00f±0.09	1028c±32
	April	25.35d±0.02	4.98cd±0.04	6.31cd±0.04	447.50e±0.53	35.60d±0.03	0.81c±0.03	23.55b±0.09	0.19de±0.05	0.51d±0.03	42.50b±0.11	12.75c±0.06	1250b±50
	May	28.85b±0.05	4.28f±0.06	6.36bc±0.03	661.50c±0.93	40.13c±0.02	1.16a±0.02	24.30a±0.05	0.26bc±0.06	0.87a±0.03	40.75d±0.08	15.00b±0.12	1500a±40
	June	29.42a±0.03	4.26f±0.04	6.35bc±0.03	716.80a±0.51	42.36a±0.02	0.92b±0.02	22.58c±0.09	0.23bcd±0.03	0.70c±0.03	39.20d±0.06	17.20a±0.07	1300b±30
	July	28.15c±0.03	4.50e±0.03	6.37b±0.02	669.50b±0.96	34.55e±0.03	0.63d±0.03	19.70f±0.07	0.20cde±0.03	0.80b±0.03	38.50e±0.04	12.50d±0.06	1100c±50
Group III (140/m^2)	**October**	23.80e±0.02	4.93c±0.04	6.67a±0.04	331.50h±0.92	22.42h±0.04	0.16h±0.02	7.01g±0.02	0.62a±0.04	0.10f±0.02	25.67f±0.08	4.17h±0.02	763e±37
	January	21.87g±0.03	5.00b±0.02	6.38cd±0.02	478.67f±1.25	33.97c±0.04	0.28g±0.04	16.43f±0.04	0.43b±0.03	0.21e±0.03	28.33e±0.07	9.33e±0.03	800e±30
	February	21.05h±0.04	4.98bc±0.05	6.30d±0.04	502.25e±1.69	31.35d±0.04	0.39f±0.03	21.60e±0.03	0.20c±0.05	0.21e±0.05	42.00a±0.09	6.00g±0.04	1800b±50
	March	22.30f±0.04	5.00b±0.04	6.31d±0.12	542.25d±0.91	42.80a±0.06	0.75e±0.02	22.23d±0.02	0.13d±0.03	0.32d±0.03	41.50b±0.07	8.00f±0.03	2000a±40
	April	25.23d±0.03	5.40a±0.03	6.49b±0.03	417.50g±1.43	38.68b±0.05	0.98c±0.03	22.15d±0.03	0.13d±0.03	0.48c±0.04	40.00d±0.08	14.50c±0.03	2000a±30
	May	28.48c±0.03	4.53d±0.04	6.38cd±0.05	590.25b±0.93	28.25f±0.04	1.23a±0.03	25.08a±0.03	0.21c±0.03	0.69ab±0.03	40.00d±0.11	17.00a±0.04	1200c±50
	June	29.38a±0.04	4.52d±0.02	6.45bc±0.03	592.80a±1.48	30.80e±0.02	0.81d±0.02	22.88c±0.02	0.19c±0.02	0.72a±0.03	40.80c±0.06	13.60d±0.02	1200c±20
	July	29.15b±0.04	4.55d±0.04	6.41bc±0.03	581.50c±0.91	27.25g±0.03	1.10b±0.03	24.85b±0.03	0.22c±0.03	0.65b±0.03	40.00d±0.07	16.50b±0.03	1100d±50

Each value is the mean ± SD

Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

4.2 Macro and micro elements concentration in fish effluent water

The data in Table 5 indicated that the concentration of nutrients in fish effluent in this study showed in increase in the concentrations of calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), sulfur (S), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn) from January to July. Buzby and Lin (2014) stated that the aquaponics system should be sized correctly to balance nutrient production from fish culture and nutrient uptake by plants in order to maintain nutrient balance. This result was in conformity with that of Savidov and Brooks (2004) who reported that Zn content was higher in the aquaponics system compared to that in the hydroponic system. In the study of Roosta (2014), Fe and Zn content in the aquaponic system were higher than those in the hydroponic system and the differences between the systems were significant. Rodrigo *et al.* (2018) also demonstrated that in aquaponics fish farming (using a species of Tilapia, GIFT strain (*Oreochromis niloticus*) all the nutrients sych as (P, K, Ca, Mg, S, Fe, Cu, Zn and Na) were increased during the experiment compared with the replacement water. However, it should be noted that nutrients are produced in aquaponics by the tilapia fish excretion or by the microbial breakdown of organic wastes continuously (Nelson, 2008).

Table 5: Concentration of nutrients (mg L^{-1}) in the fish effluent water

System	Month	Ca	K	Mg	Na	P	S	Co	Cu	Fe	Mn	Mo	Zn
Group I (100/m^2)	**January**	31.3g±0.04	4.1e±0.04	3.4g±0.03	45.1f±0.04	0.9e±0.05	3.1e±0.03	0.003b±0.0002	0.022c±0.004	0.017g±0.004	0.009b±0.003	0.018a±0.005	0.010g±0.008
	February	40.5e±0.04	3.3g±0.01	3.8f±0.05	45.1f±0.05	0.9e±0.04	2.2f±0.06	0.002c±0.0004	0.033b±0.002	0.136f±0.005	0.009b±0.006	0.018a±0.001	0.332f±0.003
	March	57.1c±0.03	5.1d±0.05	9.9e±0.04	54.1d±0.03	1.9b±0.04	10.5c±0.03	0.003b±0.0005	0.057a±0.007	0.796e±0.003	0.051a±0.005	0.018a±0.007	0.885e±0.004
	April	86.4a±0.08	19.8a±0.04	78.2a±0.08	98.2a±0.06	1.7d±0.02	143.9a±0.03	0.003b±0.0003	0.063a±0.003	1.413a±0.004	0.050a±0.003	0.018a±0.006	0.944d±0.002
	May	39.6f±0.05	8.3b±0.03	10.0d±0.03	55.4c±0.07	0.8f±0.04	13.1b±0.05	0.001d±0.0004	0.060a±0.005	1.085b±0.005	0.009b±0.004	0.018a±0.004	1.380b±0.04
	June	55.4d±0.06	6.5c±0.03	10.4c±0.03	53.7e±0.05	2.3a±0.03	6.7d±0.06	0.004a±0.0003	0.040b±0.006	0.993c±0.003	0.006b±0.005	0.018a±0.001	1.794a±0.005
	July	59.3b±0.05	3.5f±0.04	12.2b±0.05	62.5b±0.03	1.8c±0.02	6.7d±0.03	0.002b±0.0006	0.037b±0.007	0.908d±0.005	0.009b±0.006	0.018a±0.005	1.271c±0.002
Group II (120/m^2)	**January**	35.9g±0.04	5.6f±0.05	3.9g±0.05	44.8f±0.03	1.2f±0.03	3.4g±0.03	0.003c±0.0002	0.024d±0.003	0.017f±0.001	0.009c±0.002	0.018a±0.003	0.013f±0.004
	February	37.1f±0.07	6.2d±0.02	4.1f±0.05	43.6g±0.04	1.4e±0.03	3.6f±0.06	0.003c±0.0002	0.023d±0.004	0.017f±0.004	0.009c±0.004	0.018a±0.005	0.009f±0.007
	March	63.4d±0.04	6.1e±0.05	6.8e±0.02	49.0e±0.03	2.6a±0.04	4.8e±0.04	0.003c±0.0006	0.075a±0.006	0.271e±0.003	0.038a±0.002	0.018a±.004	0.512e±0.003
	April	73.1b±0.05	8.3c±0.05	24.0b±0.04	69.7b±0.03	2.1b±0.05	36.3a±0.04	0.003c±0.0002	0.051b±0.002	0.696d±0.007	0.027b±0.006	0.018a±0.002	0.868c±0.006
	May	45.5e±0.03	12.5b±0.04	12.0d±0.04	59.9c±0.04	0.7g±0.09	18.1c±0.05	0.002d±0.0003	0.073a±0.003	1.199b±0.004	0.009c±0.005	0.018a±0.004	0.814d±0.003
	June	78.5a±0.04	13.3a±0.04	38.7a±0.05	77.8a±0.02	2.0c±0.03	61.1b±0.04	0.005a±0.0003	0.054b±0.002	1.243a±0.006	0.011c±0.003	0.018a±0.001	1.681a±0.002
	July	68.3c±0.05	1.0g±0.08	12.5c±0.04	59.6d±0.03	1.5d±0.02	6.6d±0.03	0.004b±0.0003	0.041c±0.006	0.883c±0.006	0.009c±0.004	0.018a±0.002	1.544b±0.004
Group III (140/m^2)	**January**	30.7g±0.08	4.2g±0.03	3.6g±0.04	42.7g±0.06	1.1g±0.04	3.1g±0.03	0.003c±0.0002	0.021d±0.003	0.017f±0.002	0.009a±0.003	0.018a±0.003	0.008f±0.007
	February	37.0f±0.04	5.5f±0.07	4.0f±0.06	42.9f±0.06	1.4f±0.03	3.5f±0.04	0.003c±0.0005	0.022d±0.003	0.017f±0.004	0.009a±0.006	0.018a±0.007	0.011f±0.003
	March	61.1e±0.03	5.7e±0.03	6.2e±0.05	47.2e±0.05	2.2c±0.05	4.1e±0.03	0.003c±0.0004	0.043c±0.002	0.359e±0.008	0.009a±0.007	0.018a±0.009	0.443e±0.002
	April	70.9c±0.04	7.4d±0.02	33.8c±0.07	71.7c±0.05	1.7d±0.06	54.1c±0.04	0.003c±0.0003	0.052b±0.007	0.973d±0.001	0.009a±0.002	0.018a±0.005	1.119c±0.005
	May	76.6b±0.04	23.3a±0.05	59.4a±0.03	88.7a±0.04	1.6e±0.03	105.1a±0.03	0.004b±0.0004	0.061a±0.004	1.377b±0.003	0.011a±0.005	0.018a±0.005	1.096d±0.007
	June	85.1a±0.04	17.6b±0.03	43.7b±0.03	84.0b±0.07	2.9b±0.04	69.4b±0.05	0.005a±0.0004	0.054b±0.002	1.554a±0.002	0.013a±0.003	0.018a±0.003	2.443a±0.002
	July	64.7d±0.05	16.5c±0.03	13.5d±0.07	60.1d±0.04	3.8a±0.05	9.9d±0.04	0.003c±0.0006	0.039c±0.004	0.997c±0.003	0.007a±0.003	0.018a±0.002	1.766b±0.003

Each value is the mean ± SD

Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

4.3 Tilapia production

The growth parameters for the fish in the aquaponics system are given in Table 6. The highest mean group weight gain was 175.98 units in Group I (stocking rate of 100 kg/m^3) after 4 month, 273 in the Group II after 8 month (stocking rate of 120 kg/m^3) and 265 for Group III after 8 months (stocking rate of 140 kg/m^3). The average weight/fish (g) was highest in the end of the experiment after 8 months and was 0.269, 0.319 and 0.410 g for Group I, II and III, respectively. The differences in mean group weight gain were statistically significant ($p < 0.05$) and the highest weight gain was in Group II with the highest fish density after the 8 month period. Feed conversion ratio (FCR) differed significantly among the groups ($p < 0.05$). However, the FCR was similar in Group II and III. The FCR was highest in Group I.

In this aquaponics system, three different stocking rate of tilapia were analysed for i) weight gain (kg), ii) average weight/fish (g) and iii) Feed Conversion Ratios (FCR) and all fish were fed with the same feed. We observed that the growth parameters were better in the group having the maximum fish density with 140 kg/m^3. Nevertheless, tilapia in oxygenated water can be grown at the 120 kg/m^3 by providing better nutrient supply (Monsees *et al.,* 2017). FCR is one of the most import parameters in terms of economy of the aquaponics system should be optimized together with fish density and feeding ratio. Thus, in our case, the minimum FCR of 0.67 was observed in the group III with the highest stocking rate (140 kg/m^3). Monsees *et al.* (2017) found an average FCR of 1.2 to 1.3 in a coupled system with 40 kg fish/m^3 and considered this as favourable commercial aquaculture. Endut *et al*. (2016) reported that FCR values of between 1.23–1.39 for catfish (*Clarius gariepinus*) in an aquaponics system with stocking ratio of 25 kg/m^3 at different flow rates. They considered this as ideal for aquaculture. Thus, in our study the FCR observed in the all groups (Table 6) are similar to the economic FCR values in aquaculture.

Table 6: The growth parameters for the fish, number of fish, weight of fish, weight gain and average fish per fish Aquaponics fish growth rate, weight increment and feed consumption

System	**Months**	**No of fish**	**Weight of fish (kg)**	**weight gain (kg)**	**Ave. Wg/fish (gm)**	**Consumed feed (kg)**	**FCR (%)**
Group I (100/m2)	**Initial**	1600a±24	19.55e±0.12	0d±0	0.012e±0.002	0d±0	0c±0
	2 month	1524bc±19	96.87d±0.03	77.32c±0.09	0.063d±0.003	175c±6	1.80a±0.02
	4 month	1585a±12	272.85b±4.31	175.98a±4.34	0.172b±0.005	285b±8	1.04b±0.03
	6 month	1540b±11	252c±15	-20.85e±10.69	0.163c±0.003	0d±0	0c±0
	8 month	1507c±7	405.5a±7.7	153.5b±22.7	0.269a±0.004	410a±9	1.01b±0.09
Group II (120/m2)	**Initial**	1600b±7	24.6e±0.12	0e±0	0.015e±0.003	0d±0	0d±0
	2 month	1537c±14	138.8d±1.4	114.2c±1.28	0.090d±.003	250c±8	1.80a±0.03
	4 month	1530c±9	285c±14	146.2b±15.4	0.186b±0.006	350b±9	1.22b±0.07
	6 month	1864a±13	327b±16	42d±2	0.175c±0.003	0d±0	0d±0
	8 month	1879a±17	600a±21	273a±5	0.319a±0.003	450a±11	0.75c±0.06
Group III (140/m2)	**Initial**	1600c±13	39.75e±0.27	0c±0	0.024e±0.004	0d±0	0d±0
	2 month	1573d±9	195d±92	155.25ab±92.27	0.123d±0.003	200c±13	1.02a±0.05
	4 month	1610c±13	435c±13	240a±105	0.270b±0.009	330b±15	0.75b±0.04
	6 month	2172a±14	550b±17	115b±4	0.253c±0.006	0d±0	0d±0
	8 month	1983b±12	815a±8	265a±9	0.410a±0.007	550a±11	0.67c±0.06

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

4.4 Tomato production

4.4.1 No of flowers and branches

The number of flowers and branches are presented in Table 7. The difference between the number of flowers and branches during the study period was significant at ($p \leq 0.05$). In Group I, The highest number of flowers (25) and branches (5) were observed I Group 1 in February with the treatment having 2 plants then decreased with time in March and April. The number of flowers and branches in Group II were higher than those of Group I and showed the same trend with the treatment having 2 plants. The number of flowers and branches in Group III were lower than those of Group I. In this study the highest number of flowers and branches were observed in Group II when the treatment had 2 plants. These traits decreased in number as the number of plants increased to 3 and 4.

Table 7: Number of flower and branches observed in tomato plants during the experiment period

Months	**No. of plant**	**Group I (100 kg/m^3)**		**Group II (120 kg/m^3)**		**Group III (140 kg/m^3)**	
		No. Flower	**No. Branch**	**No. Flower**	**No. Branch**	**No. Flower**	**No. Branch**
February	**2 plants**	24.00a±1.37	4.67a±1.00	25.00a±1.33	4.33ab±0.67	27.33a±0.67	5.00a±1.33
	3 plants	23.33c±1.67	4.00ab±1.67	14.67c±1.33	3.00ab±2.00	23.33d±1.67	3.33ab±1.67
	4 plants	22.67c±0.66	3.67b±0.67	14.33c±0.67	2.33b±1.67	23.67cd±0.33	3.33ab±0.67
March	**2 plants**	22.00b±1.00	4.33a±1.00	19.33b±1.67	5.00a±1.00	26.00ab±0.67	5.00a±2.00
	3 plants	19.67c±1.00	2.33b±1.67	14.00c±1.00	2.33b±0.67	24.33bcd±1.67	3.33ab±0.67
	4 plants	19.00c±1.34	2.33b±0.67	13.33c±0.67	2.33b±0.67	23.67cd±0.33	2.67ab±1.33
April	**2 plants**	21.33b±1.34	4.67ab±0.33	19.00b±2.00	4.75a±0.25	25.50abc±1.50	3.67ab±1.33
	3 plants	19.67c±1.67	3.33b±0.67	14.67c±0.66	4.00ab±2.00	24.25bcd±0.75	3.00ab±1.00
	4 plants	18.67c±0.33	2.67b±0.67	14.33c±0.67	3.25ab±0.75	23.00d±2.00	2.33b±0.67

Each value is the mean ± SD

Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

4.4.2 Plant height and width of tomato

There was a significant difference ($p<0.05$) between plant height and width during the experiment time in all 3 Groups (Table 8). The plant height and width of the tomato were higher with treatments having 2 plants (29.81 & 34.98 mm) in Group 1. In treatments with 3 and 4 plants the plants were shorter and the tomatoes had a lesser width. The highest mean values of plant height and width of tomato were observed in May then the plant appearsshorter with time-. Group II and III recorded the same trend of Group I, A fish density of 120 kg/m^3 realized the highest mean plant height and width of tomato. Castro *et al.* (2006) found that cherry tomato irrigated with fish effluent enhanced tomato growth parameters in the first three analyzed harvest period.

Table 8: Average height and average width of tomato during the experiment period

Month	**No. of plant**	**Group I (100 kg/m^3)**		**Group II (120 kg/m^3)**		**Group III (140 kg/m^3)**	
		Ave. height (mm)	**Ave. width (mm)**	**Ave. height (mm)**	**Ave. width (mm)**	**Ave. height (mm)**	**Ave. width (mm)**
March	**2 plants**	27.72bc±0.24	31.77b±0.31	28.53abc±0.89	32.04b±0.72	29.07bc±1.38	33.32cd±0.89
	3 plants	26.43bc±1.03	28.58f±0.07	27.51cde±0.92	29.76cd±1.67	27.84cde±0.50	31.54e±0.80
	4 plants	19.51e±0.52	20.30i±0.24	24.00g±1.34	24.90f±0.42	26.76e±0.59	28.64f±0.55
April	**2 plants**	29.33a±0.40	34.34a±0.29	29.59ab±0.64	34.49a±1.06	29.81ab±1.24	34.98ab±0.34
	3 plants	27.26bc±0.14	30.88cd±0.86	28.42bc±1.01	31.13bc±1.30	28.44b-e±1.10	32.30de±0.93
	4 plants	23.77d±1.34	26.58g±0.23	26.64def±1.32	28.51de±0.53	27.48cde±0.92	29.40f±1.03
May	**2 plants**	29.37a±0.66	34.11a±0.64	30.14a±0.84	35.35a±0.82	30.99a±0.57	35.83a±0.57
	3 plants	27.48bc±1.05	31.42bc±0.12	28.46bc±1.25	31.58b±0.41	28.80bcd±0.99	32.38de±0.85
	4 plants	26.29c±1.14	28.52f±0.13	27.25c-f±1.15	29.37d±0.39	27.57cde±0.52	29.70f±0.73
Jun	**2 plants**	27.10bc±0.67	34.08a±0.64	29.30ab±0.74	34.70a±1.17	29.97ab±0.90	34.38abc±1.05
	3 plants	26.94bc±1.30	30.41d±0.52	28.27bcd±1.07	31.18bc±1.25	28.41b-e±1.34	31.82de±0.51
	4 plants	23.48d±1.05	23.92h±0.42	26.47ef±0.74	27.04ef±1.08	27.34cde±1.30	29.35f±1.08
July	**2 plants**	27.91ab±1.36	31.93b±0.40	28.72abc±0.37	32.15b±0.93	29.11bc±1.54	33.99bc±1.65
	3 plants	26.69bc±1.04	29.58e±0.15	28.17bcd±0.74	31.13bc±0.15	28.33b-e±1.10	31.76e±0.67
	4 plants	23.10d±0.88	23.70h±0.16	25.72f±1.40	26.68f±0.64	27.17de±1.25	29.20f±1.23

Each value is the mean ± SD

Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

4.4.3 Tomato yield

The total tomato production with treatments having 2, 3 and 4 plants from March to July are shown in Figures 4, 5, 6 & 7 for Groups I, II and II respectively. In Group I, tomato quantity, number of tomato fruits per plant and tomato yield increased as the number of treatment plants increased from 2 to 4 plants from March to April. Thereafter these parameters decreased in the following months. The highest mean values for tomato quantity, number of tomato fruits and tomato yield occurred in April. The tomato quantity ranged between 32 to 88.4, number of fruit per plant from 1604.63 to 3743.40 and tomato yield from 1600.00 to 2210.00 with 2 and 4 plants, respectively (Figures 4, 5, 6 & 7).

In Group II, tomato quantity, number of fruit and tomato yield had the highest mean values with 4 plants in April (117.65 for tomato quantity, 6643.96 for number of tomato and 2941.25 for tomato yield) then decreased during the following months

(Figures 4, 5, 6 & 7). The average mean values of three parameters were higher in Group II than in Group I. Similar trends were observed in Group III (Figures 4, 5, 6 & 7) for the three measured traits. In summary, Group II recorded the highest values for tomato quantity, number of fruits and tomato yield in April.

On the other hand, the average weight of the tomatoes decreased with increasing number of treatment plants and from April to July. In Group I, the highest mean value of 21.50 with 2 plants in April decreased to 13.19 with 4 plants in July. Also, in Group II, the average mean values increased as the density of fish increased to 120 Kg/m^3, but the average weight decreased with increasing treatments of plants.

As for Group III (120 Kg/m^3) generally recorded the highest values of tomato average, while the average weight of tomatoes decreased with increasing number of plant.

Leafy plants are best for trapping nitrogen from the wastewater but its growth can be impaired if sufficient nitrogen is not available (Chen *et al*., 2004). The plant will grow rapidly with aquaponic system through dissolved nutrients from fish excretions and nutrients generated from the microbial breakdown of fish wastes (Bishop *et al*., 2009)

Above results are agree with those of Castro *et al.* (2006) found that irrigation with fish effluent enhanced tomato fruit number and productivity in the first three analyzed harvest periods. However, the increase in fruit number in treatments that received fish effluent resulted in lower mean fruit weight. They found that even with reduction on fruit mean weight, the increase in fruit number was enough to elevate the total productivity. Prinsloo and Schoonbee (1987) also observed an increase in tomato yield from 64.5 to 95.8 t ha^{-1} when plants were irrigated with fish effluent in comparison with plants which were irrigated with well water.

Resch (1995) indicated that hydroponic yield may vary from 200 to 700 t/ha in greenhouses under controlled conditions (humidity, light, air exchange, etc.).

McMurtry *et al.* (1997) achieved round tomato yields ranging from 93-137 t/ha in cultures with different treatments coupled with hybrid tilapia. Mariscal-Lagarda *et al.* (2014) estimated a yield of 36.1 t/ha for tomato plants irrigated with effluent from shrimp culture; the individual fruit weight was 110.6 g and there were

7.0 tomatoes per plant. However, Silva-Castro *et al.* (2006) reported a yield of 32 t/ha with an average individual fruit weight of 5.5 g for cherry tomatoes irrigated with tilapia effluent, also, on the first three harvest periods analyzed, treatments irrigated with fish effluent had higher fruit number and productivity.

Yıldız and Bekcan (2017) resulted that in aquaponic system with tilapia and tomato plants found that the fresh weight , dry weight of tomato plant and final total weight values were the maximum in Group III. Which increased with increasing fish density from 35 up to 50 kg/m^3 from fish.

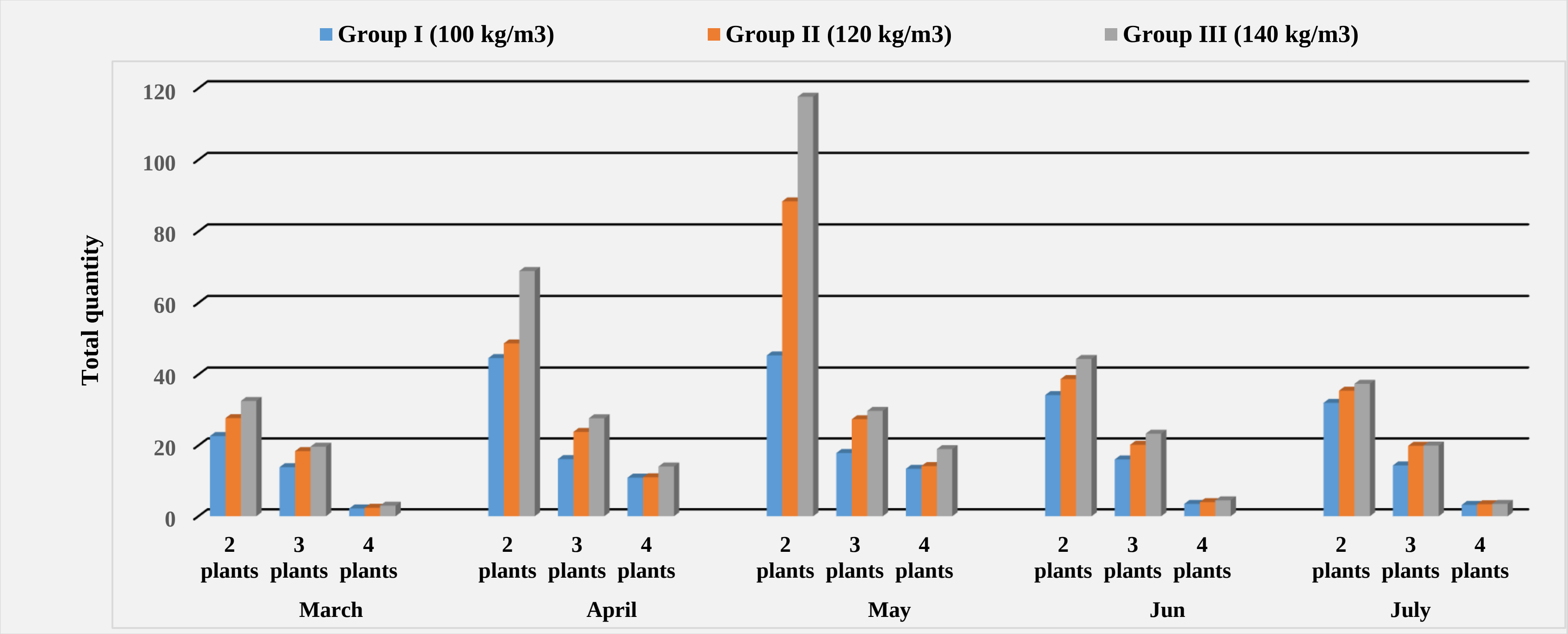


Figure 4: Monthly average total quantity of tomato in Group I, II & III

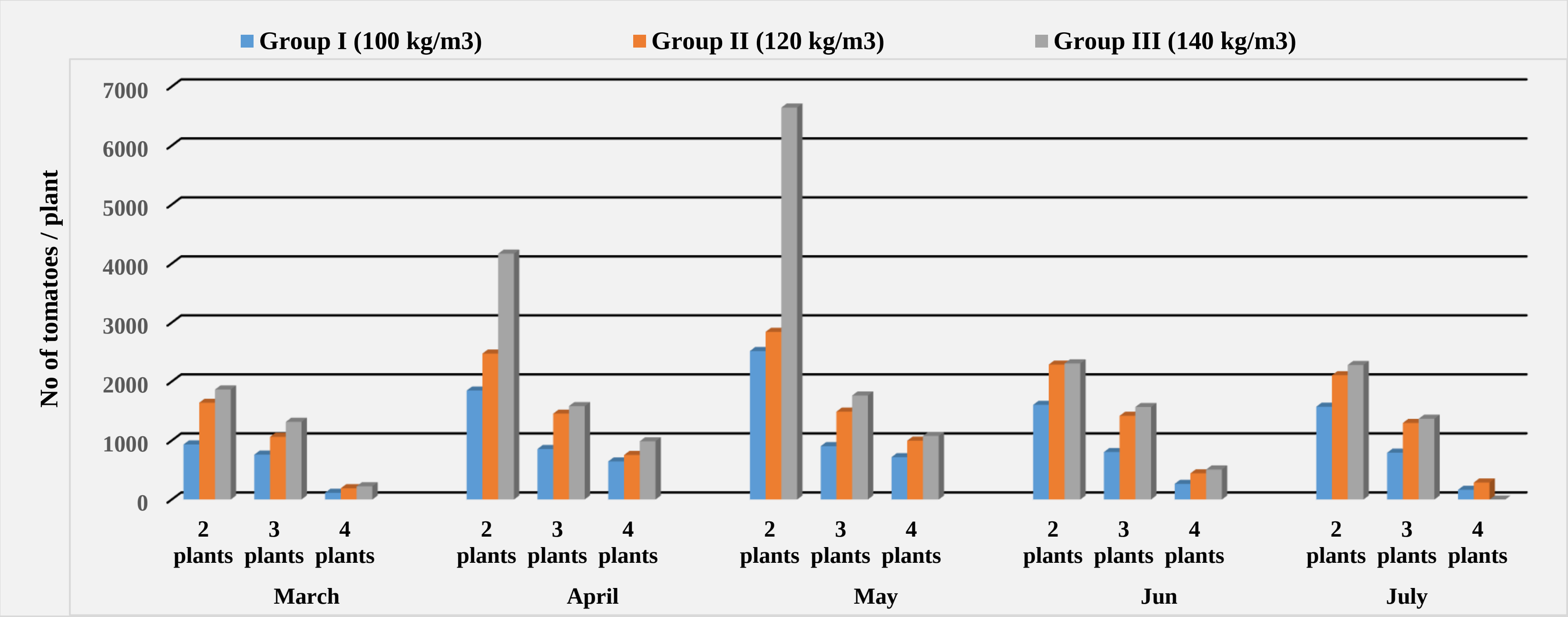


Figure 5: Monthly average No of tomatoes / plant in Groups I, II & II

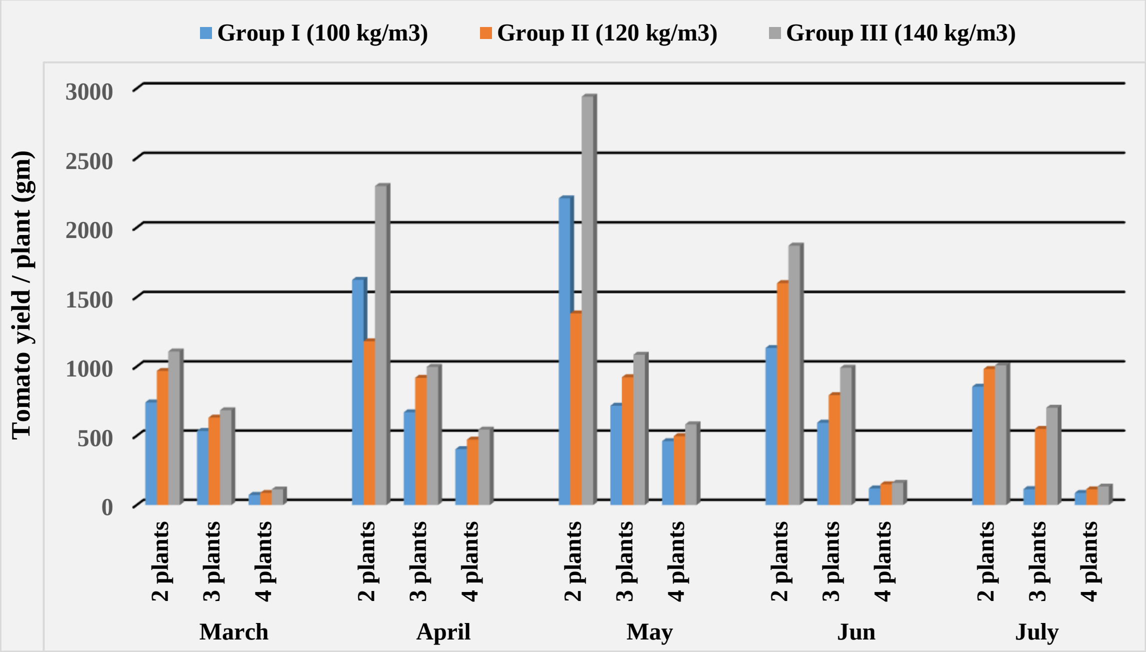


Figure 6: Monthly average tomato yield / plant (gm) in Groups I, II & III

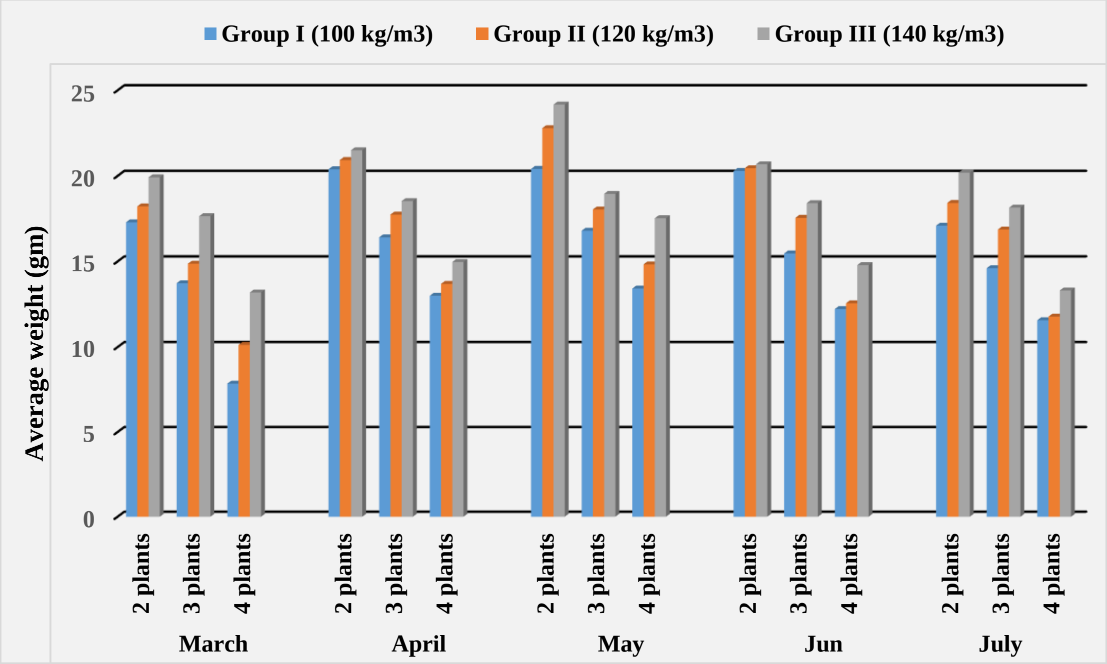


Figure 7: Monthly average weight of tomato (gm) in Groups I, II & III

4.4.4 Chemical composition

Macro and micro nutrient of tomato fruits as (Ca, Co, Cu, Fe, K, Mg, Mo, Na, P, S and Zn) in system 1, 2 and 3 during period from March to June are shown in Tables 9, 10 and 11, respectively.

There were significant differences ($p<0.05$) in Ca, Mg, K and P in tomato fruits in the 3 systems (Tables 12, 13 and 14). Ca, Mg, K and P were higher during May and the highest mean values were recorded with using 2 plants in the foam plastic. The values of Ca, Mg, K and P then decreased with an increasing number of plants/foam.

The values for Ca, Mg, K and P increased as the fish density went from 100 to 140 kg/m^3. A higher fish number increased the nutrient content in the tanks.

Table 9: Macro elements of tomato fruits during period time in Group I (100 kg/m^3)

Sampling	Group I (100 Kg/m^3) (mg/Kg (ppm)			
	Ca	Mg	K	P
2 plants	19.29d±0.04	102.33d±0.05	2038.26c±0.06	194.07d±0.03
3 plants	17.75h±0.02	98.33h±0.06	1897.11h±0.14	187.75g±0.06
4 plants	15.88k±0.01	85.27l±0.05	1651.02l±0.10	144.39l±0.03
2 plants	21.66a±0.03	111.19b±0.04	2159.95b±0.08	241.75a±0.04
3 plants	18.63f±0.03	100.20f±0.07	1945.25f±0.09	191.79e±0.04
4 plants	17.22i±0.03	92.92j±0.06	1857.87j±0.12	174.50j±0.07
2 plants	21.45b±0.03	113.80a±0.03	2276.76a±0.11	218.32b±0.07
3 plants	18.78e±0.03	100.39e±0.06	1977.82e±0.04	181.40h±0.07
4 plants	17.25i±0.07	95.08i±0.04	1883.80i±0.16	177.77i±0.06
2 plants	20.14c±0.02	110.27c±0.05	2013.69d±0.09	200.81c±0.03
3 plants	18.47g±0.04	99.67g±0.06	1926.49g±0.09	188.84f±0.09
4 plants	16.60j±0.04	91.18k±0.05	1672.69k±0.08	162.21k±0.05

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at P<0.05

Table 10: Macro elements of tomato fruits during period time in Group II (120 kg/m^3)

Sampling	Group II (120 Kg/m^3)(mg/Kg (ppm)			
	Ca	Mg	K	P
2 plants	20.31d±0.02	111.23d±0.05	2013.37e±0.14	211.94d±0.04
3 plants	18.51h±0.04	102.06h±0.07	1932.94h±0.11	202.92h±0.05
4 plants	16.38l±0.04	88.69l±0.04	1670.05l±0.18	192.89l±0.09
2 plants	22.36a±0.04	119.53b±0.04	2267.96b±0.13	215.16c±0.07
3 plants	18.78f±0.06	104.38f±0.03	2002.03f±0.20	209.38f±0.09
4 plants	17.49j±0.04	93.34j±0.04	1888.57j±0.05	197.94j±0.05
2 plants	21.72b±0.06	120.62a±0.04	2366.02a±0.11	247.23a±0.06
3 plants	19.95e±0.09	108.00e±0.04	2026.11d±0.11	211.08e±0.09
4 plants	17.65i±0.05	96.11i±0.07	1899.01i±0.20	198.90i±0.10
2 plants	20.79c±0.04	116.25c±0.04	2080.28c±0.08	215.46b±0.09
3 plants	18.61g±0.03	103.06g±0.07	1935.71g±0.05	205.30g±0.09
4 plants	17.06k±0.04	91.32k±0.03	1781.67k±0.14	197.11k±0.09

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at P<0.05

Table 11: Macro elements of tomato fruits during period time in Group III (140 kg/m^3)

Sampling	Group III (140 Kg/m^3) (mg/Kg (ppm)			
	Ca	**Mg**	**K**	**P**
2 plants	21.25d±0.04	114.88d±0.14	2262.92d±0.09	227.31c±0.08
3 plants	19.26h±0.05	103.38h±0.08	2192.55h±0.12	209.26h±0.08
4 plants	16.97k±0.05	92.69l±0.07	2145.12l±0.09	194.36l±0.15
2 plants	22.53b±0.03	120.76b±0.17	2429.61b±0.13	216.68e±0.06
3 plants	20.94e±0.05	108.20f±0.12	2249.98f±0.05	215.30f±0.09
4 plants	18.02j±0.10	98.68j±0.10	2168.64j±0.09	199.86j±0.08
2 plants	22.89a±0.04	120.96a±0.09	2487.69a±0.06	248.81a±0.12
3 plants	20.17f±0.02	109.81e±0.08	2259.27e±0.07	221.39d±0.08
4 plants	18.50i±0.06	100.63i±0.15	2179.34i±0.07	203.23i±0.11
2 plants	21.35c±0.04	120.11c±0.09	2266.39c±0.08	240.63b±0.12
3 plants	19.91g±0.03	107.35g±0.08	2231.85g±0.09	214.32g±0.16
4 plants	17.97j±0.05	98.20k±0.11	2152.11k±0.12	197.32k±0.16

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

The micro nutritional elements of the tomato fruits including Cu, Co, Mn, Mo, Na, Fe, S and Zn are presented in Tables 12, 13 and 14. All micro elements, except Co were significantly different ($p<0.05$). The micronutrient levels decreased significantly at ($p<0.05$) as the number of plants in foam plastics increased. The highest mean values for the elements were recorded in May and decreased thereafter. On the other hand, with increasing density of fish from 100 to 140 kg/m^3 increased the levels of the elements. Kloas *et al.* (2015) indicated that optimization of the aquaponics fertilizer can be established by increasing stocking densities of fish, leading to higher nutrient concentrations in aquaponics. This increases the nutrient content in the plant. The pH of the aquaponics solution had been alkaline (pH 7.7) in the present study which decreases availability and uptake of Fe, Mn, Zn and B as shown by Bertoni *et al*. (1992) and Roosta (2011).

Table 12: Micro-elements of tomato fruits during period time in Group I (100 kg/m^3)

Month	**Sampling**	**Group I (100 Kg/m^3) (mg/Kg (ppm)**							
		Cu	**Co**	**Mn**	**Mo**	**Na**	**Fe**	**S**	**Zn**
March	**2 plants**	0.56bc±0.03	0.003b-e±0.0003	0.98bc±0.02	1.31c±0.02	39.00d±0.04	2.45c±e0.03	47.71d±0.06	1.42c±0.03
	3 plants	0.46d±0.04	0.0028cde±0.0002	0.87d±0.03	1.13ef±0.02	25.83h±0.02	2.12e±0.03	46.56g±0.03	1.26ef±0.06
	4 plants	0.36f±0.03	0.0010g±0.0008	0.68e±0.02	1.02h±0.04	17.76l±0.02	1.77g±0.03	40.76k±0.05	1.09g±0.05
April	**2 plants**	0.60ab±0.04	0.0046a±0.0005	1.03ab±0.03	1.62a±0.04	51.07b±0.04	2.61b±0.08	50.10b±0.04	1.57b±0.04
	3 plants	0.53c±0.02	0.0029b-e±0.0003	0.96c±0.04	1.23d±0.05	34.61f±0.05	2.31d±0.05	47.20f±0.05	1.34cde±0.04
	4 plants	0.40ef±0.02	0.0023ef±0.0004	0.73e±0.04	1.08fgh±0.04	19.33j±0.03	1.89f±0.04	43.49i±0.04	1.16g±0.04
May	**2 plants**	0.62a±0.03	0.0036b±0.0002	1.06a±0.03	1.68a±0.06	56.78a±0.06	2.73a±0.03	51.25c±0.02	1.70a±0.08
	3 plants	0.54c±0.02	0.0034bc±0.0004	0.97bc±0.05	1.30c±0.06	37.14e±0.05	2.32d±0.05	47.36a±0.07	1.38cd±0.04
	4 plants	0.44de±0.05	0.0026def±0.0004	0.74e±0.05	1.11fg±0.03	22.18i±0.04	2.05e±0.04	44.93e±0.06	1.25f±0.04
Jun	**2 plants**	0.57abc±0.02	0.0032bcd±0.0002	1.00abc±0.04	1.38b±0.04	50.42c±0.03	2.58b±0.04	48.04h±0.04	1.53b±0.03
	3 plants	0.47d±0.05	0.0027c-f±0.0004	0.88d±0.06	1.18de±0.04	34.34g±0.02	2.28d±0.06	47.12c±0.04	1.33def±0.05
	4 plants	0.37f±0.04	0.002f±0.0009	0.71e±0.06	1.06gh±0.02	17.98k±0.06	1.86d±0.02	42.70f±0.06	1.12g±0.05

Each value is the mean ± SD

Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

Table 13: Micro-elements of tomato fruits during period time in Group II (120 kg/m^3)

Month	Sampling	Group I (100 Kg/m^3) (mg/Kg (ppm)							
		Cu	**Co**	**Mn**	**Mo**	**Na**	**Fe**	**S**	**Zn**
March	**2 plants**	0.59abc±0.04	0.0037cd±0.0007	1.08b±0.05	1.51c±0.02	50.44c±0.04	2.62bc±0.04	49.53d±0.06	1.53bc±0.02
	3 plants	0.53b-e±0.05	0.0029def±0.0004	0.98cde±0.05	1.21ef±0.04	34.70g±0.05	2.49e±0.07	46.93g±0.04	1.42de±0.03
	4 plants	0.46e±0.06	0.0012g±0.0007	0.89e±0.04	1.06h±0.06	25.02k±0.07	2.00h±0.08	41.50k±0.07	1.10g±0.08
April	**2 plants**	0.61ab±0.07	0.0048ab±0.0005	1.21a±0.03	1.70ab±0.04	51.41b±0.03	2.69b±0.04	54.45b±0.04	1.74a±0.02
	3 plants	0.57a-d±.0.05	0.0033cde±0.0003	1.02bcd±0.07	1.34d±0.05	41.93e±0.10	2.52de±0.05	47.26f±0.06	1.47cd±0.03
	4 plants	0.51cde±0.04	0.0024f±0.0005	0.95de±0.07	1.12gh±0.07	33.80i±0.09	2.18g±0.04	44.29i±0.06	1.32f±0.06
May	**2 plants**	0.63a±0.05	0.005a±0.0003	1.26a±0.05	1.78a±0.06	59.33a±0.06	2.85a±0.04	57.34a±0.05	1.76a±0.06
	3 plants	0.58abc±0.06	0.0034cde±0.0005	1.06bc±0.06	1.46c±0.06	49.95d±0.08	2.59cd±0.04	47.89e±0.04	1.51bc±0.06
	4 plants	0.52b-e±0.07	0.0027ef±0.0004	0.96de±0.06	1.17fg±0.03	34.36h±0.05	2.36f±0.09	45.24h±0.04	1.39ef±0.04
Jun	**2 plants**	0.60abc±0.07	0.004bc±0.0004	1.10b±0.04	1.63b±0.04	51.31b±0.03	2.66bc±0.04	51.50c±0.05	1.56b±0.03
	3 plants	0.54a-e±0.04	0.003def±0.0002	1.01bcd±0.05	1.27de±0.05	36.04f±0.06	2.51de±0.06	47.22f±0.06	1.43de±0.03
	4 plants	0.48de±0.05	0.0022f±0.0006	0.90e±0.09	1.07h±0.06	26.22j±0.03	2.15g±0.04	42.70j±0.08	1.14g±0.04

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

Table 14: Micro-elements of tomato fruits during period time in Group III (140 kg/m^3)

Month	**Sampling**	**Group I (100 Kg/m^3) (mg/Kg (ppm)**							
		Cu	**Co**	**Mn**	**Mo**	**Na**	**Fe**	**S**	**Zn**
March	**2 plants**	0.62ab±0.03	0.0038cd±0.0005	1.32bc±0.03	1.57c±0.03	56.01d±0.08	2.72c±0.05	53.52d±0.03	1.65c±0.04
	3 plants	0.55d±0.04	0.0030def±0.0002	1.12e±0.02	1.29efg±0.03	44.63h±0.03	2.54e±0.04	49.52h±0.03	1.50e±0.04
	4 plants	0.49a±0.05	0.0025f±0.0007	0.95f±0.04	1.11i±0.06	34.14l±0.05	2.16g±0.02	42.47l±0.02	1.24g±0.05
April	**2 plants**	0.64abc±0.04	0.0048ab±0.0005	1.36ab±0.02	1.71b±0.03	69.98b±0.04	2.79b±0.04	56.18b±0.03	1.76ab±0.04
	3 plants	0.58cd±0.05	0.0034c-f±0.0005	1.26d±0.03	1.36e±0.03	45.81f±0.05	2.61d±0.06	51.95f±0.03	1.61cd±0.05
	4 plants	0.52a±0.03	0.0027ef±0.0007	0.99f±0.04	1.23gh±0.05	36.04j±0.05	2.41f±0.03	47.86j±0.02	1.38f±0.04
May	**2 plants**	0.65ab±0.04	0.0052a±0.0007	1.41a±0.03	1.79a±0.04	75.89a±0.07	2.87a±0.05	59.02a±0.07	1.80a±0.04
	3 plants	0.61cd±0.03	0.0035cde±0.0004	1.27cd±0.02	1.48d±0.06	52.65e±0.05	2.63d±0.03	53.27e±0.03	1.64c±0.04
	4 plants	0.53a±0.06	0.003def±0.0004	1.00f±0.04	1.26fg±0.06	36.70i±0.06	2.45f±0.04	48.63i±0.03	1.46e±0.04
Jun	**2 plants**	0.63bcd±0.03	0.004bc±0.0005	1.34b±0.05	1.63c±0.04	66.04c±0.05	2.76bc±0.04	55.71c±0.03	1.72b±0.03
	3 plants	0.55d±0.03	0.0030def±0.0009	1.25d±0.03	1.32ef±0.06	44.78g±0.06	2.57de±0.03	49.63g±0.06	1.57d±0.03
	4 plants	0.50±0.07	0.0026ef±0.0002	0.97f±0.05	1.16hi±0.05	35.43k±0.05	2.40f±0.05	46.79k±0.03	1.32f±0.04

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

4.4.5 Quality of tomato

The dry matter, moisture, ash, crude protein, crude fiber and fat% during the harvest period from March to June are presented Tables 15, 16 and 17. In Group I, dry matter, moisture, ash, crude protein, crude fiber and fat% were significantly different at ($p \leq 0.05$) during harvest period from March to June (Table 15). They were higher with using 2 plants per foam in May. The same trend was observed in Group II although the values were higher (Table 16). All the traits were higher in Group III (Table 17) due to the higher density of fish. The highest mean values were obtained with using 2 plants in foam.

Generally from the result in the experiment under study it can concluded that with increasing density of fish and decrease in treatments of plant number found an increase in average values of tomato quality which mean that water recirculation between fish farming and plant cultivation provides conditions of optimization of both activities, so that, during the recirculation, the characteristics of water and fish farming environment are monitored and conditioned (Dalsgaard *et al.*, 2013). Hence, fish farming and plant cultivation occur under adequate conditions, resulting in a product with high standard of commercial quality (Dediu *et al*., 2012; Geisenhoff *et al*., 2016).

Table 15: Quality of tomato fruit during harvesting period at Group I (100 kg/m^3)

Harvest period	Sample	Dry matter%	Moisture%	Ash%	Crude protein%	Crude Fiber%	Fat%
March	**2 plants**	31.69c±0.05	71.84h±0.04	1.33bc±0.06	3.93c±0.06	2.45c±0.04	0.45bcd±0.03
	3 plants	31.12f±0.05	72.59d±0.04	1.16f±0.03	3.67ef±0.06	2.19e±0.03	0.39c-g±0.05
	4 plants	30.06j±0.05	73.27a±0.05	0.97a±0.04	3.50h±0.08	1.94f±0.05	0.32g±0.07
April	**2 plants**	32.00b±0.09	71.33j±0.06	1.46c±0.04	4.07b±0.05	2.62ab±0.04	0.52ab±0.07
	3 plants	31.35d±0.04	72.16f±0.04	1.25de±0.05	3.78d±0.04	2.39cd±0.06	0.42c-f±0.02
	4 plants	30.63h±0.03	72.81c±0.07	1.09a±0.07	3.59fgh±0.05	2.16e±0.03	0.35efg±0.03
May	**2 plants**	32.15a±0.04	71.06k±0.07	1.48c±0.04	4.24a±0.05	2.68a±0.05	0.54a±0.03
	3 plants	31.43d±0.03	71.96g±0.05	1.30d±0.03	3.88c±0.03	2.43c±0.06	0.43cde±0.06
	4 plants	30.89g±0.04	72.72c±0.05	1.12ab±**0.07**	3.61fg±0.08	2.17e±0.03	0.38d-g±0.05
June	**2 plants**	31.77c±0.05	71.58i±0.02	1.41c±0.03	3.97c±0.06	2.57b±0.03	0.47abc±0.02
	3 plants	31.24e±0.05	72.33e±0.0	1.25c±0.04	3.71de±0.06	2.31d±0.06	0.40c-g±0.08
	4 plants	30.48i±0.04	72.95b±0.08	1.02ef±0.07	3.57gh±0.04	2.12e±0.07	0.34fg±0.05

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

Table 16: Quality of tomato fruit during harvesting period at Group II (120 kg/m^3)

Harvest period	Sample	Dry matter%	Moisture%	Ash%	Crude protein%	Crude Fiber%	Fat%
March	**2 plants**	33.74bc±0.51	71.02i±0.10	1.34b±0.05	4.64c±0.04	2.53cd±0.02	0.47bcd±0.03
	3 plants	31.16de±0.27	72.03e±0.08	1.22cd±0.06	4.05f±0.05	2.30gh±0.05	0.40d-g±0.03
	4 plants	30.13f±0.09	73.20a±0.04	1.05f±0.06	3.38j±0.04	2.03j±0.07	0.34g±0.04
April	**2 plants**	34.97a±0.7	70.54k±0.04	1.48a±0.05	4.81ab±0.08	2.63b±0.03	0.54ab±0.05
	3 plants	33.14c±0.15	71.56g±0.03	1.27bc±0.04	4.33e±0.04	2.41ef±0.07	0.43c-f±0.03
	4 plants	31.05de±0.37	72.69c±0.04	1.11ef±0.04	3.63h±0.03	2.21i±0.07	0.36fg±0.05
May	**2 plants**	35.55a±0.20	70.29l±0.04	1.53a±0.06	4.88a±0.05	2.73a±0.03	0.57a±0.04
	3 plants	33.40c±0.14	71.24h±0.05	1.31b±0.06	4.54d±0.05	2.46de±0.04	0.45cde±0.04
	4 plants	31.12de±0.31	72.29d±0.04	1.16de±0.04	3.90g±0.05	2.26hi±0.06	0.39efg±0.06
June	**2 plants**	34.16b±0.73	70.73j±0.04	1.46a±0.03	4.73b±0.04	2.59bc±0.05	0.49bc±0.04
	3 plants	31.43d±0.11	71.87f±0.04	1.27bc±0.07	4.10f±0.05	2.35fg±0.05	0.41d-g±0.07
	4 plants	30.63ef±0.41	72.91b±0.07	1.08ef±0.04	3.48i±0.04	2.18i±0.05	0.35g±0.02

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

Table 17: Quality of tomato fruit during harvesting period at Group III (140 kg/m^3)

Harvest period	Sample	Dry matter%	Moisture%	Ash%	Crude protein%	Crude Fiber%	Fat%
March	**2 plants**	34.19d±0.04	70.59c-f±0.27	1.41cd±0.02	4.93±0.06	2.59d±0.04	0.48cd±0.04
	3 plants	33.37h±0.03	71.57a-d±0.11	1.23fg±0.06	4.47±0.03	2.32g±0.06	0.41fg±0.03
	4 plants	32.68l±0.03	72.28a±0.19	1.12h±0.06	4.09±0.03	2.15j±0.04	0.36h±0.04
April	**2 plants**	35.04b±0.07	69.93ef±0.28	1.51ab±0.05	5.32±0.07	2.68b±0.05	0.56b±0.03
	3 plants	33.87f±0.04	71.04a-e±1.17	1.34de±0.05	4.69±0.04	2.49f±0.03	0.44e±0.03
	4 plants	33.01j±0.06	71.89abc±0.21	1.16gh±0.05	4.29±0.03	2.27hi±0.05	0.39g±0.04
May	**2 plants**	36.02a±0.06	69.48f±0.64	1.57a±0.5	5.61±0.04	2.76a±0.03	0.58a±0.04
	3 plants	34.07e±0.04	70.81b-f±0.97	1.39cd±0.06	4.82±0.05	2.53e±0.03	0.45de±0.04
	4 plants	33.25i±0.04	71.82abc±1.09	1.19gh±0.04	4.31±0.07	2.29h±0.05	0.39g±0.04
June	**2 plants**	34.65c±0.04	70.23def±1.09	1.47bc±0.06	5.19±0.04	2.61c±0.03	0.50bc±0.05
	3 plants	33.74g±0.02	71.36a-d±1.07	1.29ef±0.03	4.55±0.04	2.37g±0.07	0.43f±0.06
	4 plants	32.84k±0.04	72.07ab±1.06	1.15gh±0.04	4.22±0.04	2.19i±0.03	0.37h±0.03

Each value is the mean ± SD
Mean values in each column have different subscript (a, b, c, d……..) are significant different at $P<0.05$

Chapter 5: Summary

This study was carried out in the PVC (polyvinyl chloride) greenhouse on the area reserved for experiments in the College of Food and Agriculture at Falaj Hazza campus ALA in, UAE. In this study a small-scale aquaponics system with a grow bed form producing tilapia (*Oreochromis aureus*) and tomato (*Solanum lycopersicum*) were used as the fish and the plant materials, respectively.

Treatments were arranged in complete randomize block design with 3 replicates as follows. Tilapia (*Oreochromis niloticus*) were stocked at different ratios: 100 kg/m^3 (Group I), 120 kg/m^3 (Group II) and 140 kg/m^3 (Group III). Tomato plants were sown in vegetation foam plates each with 2, 3 or 4 plantlets.

The obtained results could be summarized as follows:

5.1 Water quality

Water quality parameters including temperature, DO, pH, TDS, EC, ammonium, nitrite, nitrate, iron, alkalinity, acidity and light intensity except water temperature showed significant differences ($p<0.05$) with times and the experimental groups.

Ammonium levels varied between 0.10 and 1.08 mg/L in Group I, 0.24 and 1.16 mg/L in Group II and 0.16 and 1.23 mg/L in Group III. Nitrate levels were between 5.90 and 22.40 mg/L in Group I, 5.95 and 24.30 in Group II and 7.01 and 25.08 mg /L in Group III. Nitrite levels ranged from 0.09 to 0.22 mg/L in Group I, from 0.14 to 0.29 mg/L Group II and from 0.13 to 0.62 mg/L in Group III. Iron values in water ranged from 0.10 to 0.68 mg/L in Group I, from 0.09 to 0.87 mg/L in

Group II and from 0.10 to 0.72 mg/L in Group III. Alkalinity during the experiment varied between 25.33 to 43.75 in Group I, 24.50 to 42.50 in Group II and 25.67 to 42.00 in Group III. Acidity ranged between 2.80 to 16.25 in Group I, 4.83 to 17.20 in Group II and 4.17 to 17.00 in Group III. Finally, light intensity (Lux) ranged between 950 to 1250 in Group I, 750 to 1500 in Group II and 763 to 2000 in Group III. The EC values found in the present study were higher.

5.2 Macro and micro elements concentration in fish effluent water

The concentration of nutrients in fish effluent in this study showed an increase in the concentrations of calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), sulfur (S), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn) from January to July.

5.3 Tilapia production

The highest mean group weight gain was 175.98 units in Group I (stocking rate of 100 kg/m^3) after 4 month, 273 in the Group II after 8 month (stocking rate of 120 kg/m^3) and 265 for Group III after 8 months (stocking rate of 140 kg/m^3). The average weight/fish (g) was highest in the end of the experiment after 8 months and was 0.269, 0.319 and 0.410 g for Group I, II and III, respectively. The differences in mean group weight gain were statistically significant ($p < 0.05$) and the highest weight gain was in Group II with the highest fish density after the 8 month period. Feed conversion ratio (FCR) differed significantly among the groups ($p < 0.05$). However, the FCR was similar in Group II and III. The FCR was highest in Group I.

5.4 Tomato production

5.4.1 No of flowers and branches

In this study the highest number of flowers and branches were observed in Group II when the treatment had 2 plants.

5.4.2 Plant height and width of tomato

The highest mean values of plant height and width of tomato were observed in May then the plant appearsshorter with time. A fish density of 120 kg/m^3 realized the highest mean plant height and width of tomato.

5.4.3 Tomato yield

The highest mean values for tomato quantity, number of tomato fruits and tomato yield occurred in April. Group II recorded the highest values for tomato quantity, number of fruits and tomato yield in April. On the other hand, the average weight of the tomatoes decreased with increasing number of treatment plants and from April to July.

5.4.4 Chemical composition

Ca, Mg, K and P were higher during May and the highest mean values were recorded with using 2 plants in the foam plastic. The values of Ca, Mg, K and P then decreased with an increasing number of plants/foam. The values for Ca, Mg, K and P increased as the fish density went from 100 to 140 kg/m^3 . A higher fish number increased the nutrient content in the tanks.

The micronutrient levels decreased significantly at ($p<0.05$) as the number of plants in foam plastics increased. The highest mean values for the elements were recorded in May and decreased thereafter. On the other hand, with increasing density of fish from 100 to 140 kg/m^3 increased the levels of the elements.

5.5 Quality of tomato

The dry matter, moisture, ash, crude protein, crude fiber and fat% were higher in Group III. The highest mean values were obtained with using 2 plants in foam.

Chapter 6: Conclusion

This study was carried out to assess the optimum planting density for tomato (*Solanum lycopersicum*) production in an aquaponic system with different fish densities and different number of pants.

A significant difference was observed in the numbers of branches, flowers and tomato production among the three treatments. The number of branches and flowers was highest in Group III when 2 plants were used. It decreased as the number of plant increase from 3 to 4 in dishes. Plant height and width of the tomato had the highest mean values with a fish density at 140 kg/m^3. The yield of tomato indicated that Group III recorded the highest values for tomato quantity, number of tomatoes per plant and tomato yield in May month by using 2 plants in the foam.

Macro and micro-elements (Ca, Mg, K and P as well as Cu, Co, Mn, Mo, Na, Fe, S and Zn) were higher during May and the highest mean values were recorded at a planting density of 2 plants per foam and decreased with increasing number of plants/foam. On the other hand with increasing density of fish from 100 to 140 kg/m^3, the elements under investigation also increased.

The effects of stocking rate were determined for the tilapia growth and plant biomass. The growth performance and feed conversion assessed in this study were better in the group with the maximum density (initial stocking rate, 140 kg/m^3). The total plant biomass was found to be highest with this density. The most important factor was to control the water quality, particularly pH and nitrogenous substances.

It can concluded that under the specified conditions of this investigation, it could be recommended that a fish stocking density of 140 kg/m^{3}and a planting density of 2 plants per foam showed the highest yield of tomato and perhaps will have the most beneficial economic evaluation.

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