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Effect of Feeding Frequency and Stocking Density on Tilapia Oreochromis Niloticus and Lettuce Lactuca Sativa Production in Aquaponics System under the UAE Condition and Business Enterprise Analysis

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Declaration of Original Work

I, Ahmed Abdelrahman Mohamed Abdelrahman, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Effect of Feeding Frequency and Stocking Density on Tilapia Oreochromis Niloticus and Lettuce Lactuca Sativa Production in Aquaponics System Under the UAE Condition and Business Enterprise Analysis*", 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. Ibrahim Hassan Belal, in the College of Food and Agriculture at the UAEU. This work has not previously been presented or published or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation, or publication of this thesis.

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Abstract

This thesis was carried out to investigate the impact of various Tilapia (*Oreochromis niloticus*) feeding frequency and stocking density on quality and quantity of organic lettuce that is produced in an aquaponic system, knowing that they affect the nutrient content in water. Business analysis through enterprise budget was developed considering different feeding frequency and stocking density of the fish to predict the business efficiency of the system, and the net incomes were as high as AED 34,394 and AED 46,637, respectively. On the other hand, lettuce was seeded in a culture raceway. The duration of the experiments was decided to be six months, which was divided into two parts to study each parameter, i.e. feeding frequency (Once, twice and three times per day) and stocking density (100,120,140 fishes per cubic meter). In parallel, the aquaponic system water quality (pH, temperature, total dissolved solids, dissolved Oxygen, total ammonia, nitrite, and nitrate) and water consumption were analysed at specified intervals. Furthermore, fish and cultivated plant growth rate and total yield were analysed at the first and last days of the experimental period. The purpose of that was to optimise the system feeding system and stocking from different approaches both agriculturally and economically. It was found that highest used feeding frequency and stocking density are recommended to achieve high profitability.

Keywords: *Oreochromis niloticus*, aquaponic system, feeding frequency, stocking density, enterprise budget analysis, the UAE.

Title and Abstract (in Arabic)

تأثير الكثافة المختلفة لاسماك البلطي النيلي وتكرار التغذية على إنتاجية الأسماك ونبات الخس في نظام الاكوابونيك تحت ظروف دولة الإمارات مع التقييم الاقتصادي

الملخص

تشكل أزمة ندرة الغذاء في بعض مناطق العالم إلى جانب الحاجة لتوفير موارد غذائية جديدة اهتماماً متزايداً لدى صناع الأغذية في العالم، وتشهد أنظمة الأكوابونيك تطوراً كبيراً كمصدر جديد للصناعة الغذائية، حيث توفر مثل هذه الأنظمة إمكانية إنتاج أسماك وخضروات متعددة في حيز مكاني واحد؛ لذا تهدف هذه الأطروحة البحثية التعرف على أنسب عدد مرات التغذية اليومية لسمك البلطي النيلي *Oreochromis Niloticus* ، إلى جانب معرفة أفضل كثافة للأسماك في المتر المكعب الواحد، و ذلك في نظام الأكوابونيك المستخدم لإنتاج سمك البلطي و الخس في آن واحد، إلى جانب التعرف على تأثير هذين العاملين المهمين على جودة منتجات هذا النظام، علماً أنهما يؤثران على المحتوى الغذائي للمياه التي تعيش فيها الأسماك، وقد تم إجراء التجربة على ثلاث مراحل لكل منها عدد مرات تغذية يومية مختلف وهي: (مرة، مرتان، ثلاث مرات يومياً) و ثلاث مراحل أخرى لكل منها كثافة أسماك في المتر المكعب مختلفة وهي: (100، 120، 140) سمكة لكل متر مكعب، كما تم إجراء تحاليل دورية لاختبار جودة المياه في الأحواض، فضلاً عن إجراء دراسة جدوى مالية باستخدام طريقة Enterprise Budget Analysis لدراسة عاملي التغير في عدد مرات التغذية و كثافة الأسماك على المردود المالي و الكفاءة الاقتصادية لهذا النظام، فكانت نتيجة ذلك من ناحية المدخلات المالية 34,394 درهماً و 46,637 درهماً على الترتيب عند أعلى عدد مرات تغذية يومية و أعلى كثافة للسمك في المتر المكعب الواحد.

مفاهيم البحث الرئيسية: نظام الأكوابونيك، تربية الأسماك، تكرار التغذية، كثافة الأسماك ، تحليل الجدوى الاقتصادية، دولة الإمارات العربية المتحدة.

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Dedication

To my mother for the support and continuous prayers, to all my beloved family,
To my mentors Dr. Ibrahim H. Belal and Dr. Eihab Fathelrahman for being a source of knowledge and inspiration

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List of Abbreviations

AED	United Arab Emirates dirham
DO	Dissolved oxygen
DWC	Deep-water culture
FCR	Feed conversion ratio
FI	Feed intake
NFT	Nutrient film technique
PER	Protein efficiency ratio
RAS	Recirculating aquaculture systems
TAN	Total ammonia nitrogen
TDS	Total dissolved solids
UAE	United Arab Emirates
UVI	University of the Virgin Islands
WG	Weight gain

Chapter 1: Introduction

1.1 Overview

Aquaponic systems are considered as fast emerging food production technology, it integrates recirculating aquaculture with hydroponics (Rakocy *et al*., 2004) into a commonly closed-loop ecoculture where water and other nutrients are recirculated and reclaimed (Diver, 2006; Rakocy *et al*., 2006; Endut *et al.,* 2010; Love *et al*., 2015). In aquaponic systems, the wastewater from aquaculture system that is rich in nutrients is circulated to vegetable grow beds in a hydroponics system. As the effluent from fish flows through the hydroponic system, microbes break down fish waste metabolites into soluble nutrients. Thus plants can uptake nutrients directly from water. Already treated, cleansed and safe water for the fish flows back to aquaculture system for reuse (Rakocy *et al*., 2006; Somerville *et al.,* 2014).

Aquaponics productions are known to be natural, organic, eco-friendly and free of pesticides and herbicides (Blidariu & Grozea, 2011). Other advantages are: less usage of water through reuse, the recycling of nutrients and management of waste, and minimise adverse environmental impacts such as pollution (McMurtry *et al*., 1997; Al-Hafedh *et al*., 2003; Rakocy *et al.*, 2004). In addition to the ecological benefits, aquaponics system are capable of offering several economic benefits such as: savings in the costs of the treatment of water in the aquaculture system, formulation of novel fertilizer for the hydroponics system and increasing returns from both harvest of fishes and vegetables, using one input, i.e. fish feed (Alder *et al.*, 2000; Liang & Chien, 2013).

The mostly grown plants in aquaponics include lettuce, water spinach, tomato, cucumber, pepper and herbs (Rakocy & Hargreaves, 1993; Alder *et al.*, 2000; Savidov *et al.*, 2005). Among those, Lettuce (*Lactuca sativa*) is commonly used because it is well adapted to aquaponic systems. It can be harvested within 3 to 4 weeks, with relatively fewer pest problems and low to medium nutritional requirements (Diver, 2006; Rakocy *et al*., 2006). Furthermore, several types of fish are used in the fish fragment of the system. Nile Tilapia (*Oreochromis Niloticus*) is a prevalent fish raised in such systems (Rakocy *et al*., 2006). This is because of its obtainability, quick growth, easily cultivable nature, stress and diseases resistant and adaptability in indoor environments (Hussain, 2004; Rakocy *et al.*, 2006). Tilapia *O. niloticus* can tolerate different and varying conditions of a temperature of water, water salinity, pH, dissolved oxygen in the water, photoperiods and light intensity. It can also tolerate to stress by handling (Hussain, 2004; Yue & Zhou, 2008), and to poor water quality and fluctuating water conditions. Moreover, it is capable of showing various feeding regime (Bowen & Allanson, 1982; Maitipe & De Silva, 1985).

1.2 Relation to the UAE

The climate in the UAE is desert climate with low rainfall and extremely high summer temperatures. Like most countries in the Arabian Peninsula, UAE is facing freshwater shortages. Also, with the rapid population growth the demand for water and food production increases. UAE has limited renewable water resources which becoming increasingly scarce (Murad *et al.*, 2007; Shahin & Salem, 2015). Over-irrigation, inefficient water usage, improper irrigation systems, cultivation of water-intensive crops and inappropriate water management practices led to water scarcity that is associated with wastage of water (Murad *et al.*, 2007; Shahin & Salem, 2015). Therefore, the efficient water use is needed to ensure its sustainability, which could be addressed through adopting modern farming methods and technologies, thereby the food security can be ensured throughout the country.

The UAE relies on the imports of vegetables such as lettuce, tomatoes, cucumbers, and he like that often vulnerable to price and supply shocks. Therefore, aquaponics could be a practical solution for water-saving technology and to address water scarcity issues in the region while giving high economic returns (Al Hafedh *et al.*, 2008). Also, aquaponic systems enable prolong agricultural production in the hot summer months by compensating deficit of food production, and thus, regulate higher market prices due to seasonal shortages. Thereby, it could support to ensure the country's food security through the increase of agricultural production.

Aquaponics has been already practiced in the UAE. The Baniyas centre, located in the Zayed Higher Agricultural Centre for Development and Rehabilitation in Abu Dhabi, was formed in 2011, which is one of the most extensive commercial aquaponic systems in the world. It produced 10 tonnes of fish and 60,000 tonnes of Lettuce in the first year of operation. The centre has two greenhouses for fish and vegetables with an area of 2,400 m^2 per each (Malek, 2012). In recent years, aquaponic farming has increased the share of locally produced vegetables like tomatoes, lettuce, cucumbers, and bell peppers. Also, it increased the production of fishes like tilapia and barramundi. Among them, lettuce and tilapia share most of the production for the local market. It can be concluded that Aquaponic vegetables and fish have good potential to supply local market and meet increasing demand. Statistics in 2017 show that the country imported 89% of the total lettuce consumed.

1.3 Feeding Frequency and Stocking Density

The stocking density of fish in the aquaponic system is considered as an essential factor in addition to feeding rate and frequency since it affects nutrient availability in solution inside the system. Fish feed waste is considered the primary nutrient source for plants in the hydroponic system. Stocking density was proven to have some direct effects on growth, survival, water quality and fish behaviour (De Oliveira *et al.*, 2012). Therefore, optimum stocking density is essential to achieve maximum production, efficiency and profitability. Whereas, optimum feeding rate and feeding frequency also fundamental to obtain the best production of fish and vegetables (Rahman and Marimuthu, 2010).

1.4 Objectives of the Study

To date, there is little information about the maximum feeding frequency and stocking density of tilapia production with lettuce production in the aquaponic system in the conditions of the UAE. The information gained from the current study would support local aquaponic farmers to increase efficiency, economic benefits through maximizing production. Moreover, there are few studies that was conducted to examine the economic feasibility of the aquaponics systems in the climate conditions of the Arabian Gulf. Current study would attempt to fill this knowledge gap by assessing capital and operational costs, operational costs using breakeven business analysis.

Aquaponic food production in arid climates will generate additional costs that may be due to environmental control mechanisms (i.e. greenhouses, supplementary lighting, heaters and coolers), which must be used to obtain optimal production. Although aquaponics offers several benefits, economic analysis is essential to figure out economic feasibility of the system. The current study would encourage investors to consider for investing more aquaponic farms in the UAE. There the objectives of this study were to evaluate:

a) Lettuce and fish production with three feeding frequencies in the one-month trial (feeding once, twice and three times a day to satiation level) .
b) Lettuce and fish production with three fish stocking rates (100, 120, 140 fish per cubic meter).
c) Economic evaluation of the aquaponic system using enterprise budget analysis which includes fish feed consumption, water, and electricity consumption under UAE condition.

Chapter 2: Literature Review

2.1 Overview

Enterprise budget analysis is a useful tool for understanding potential profitability and comparing costs and returns of a specific enterprise taking into account pre-decided production goals. In this analysis, the breaking down costs and revenues are calculated in each component of the system, i.e. fish and vegetables (Engle & Neira, 2005; Diver, 2006; Fern, 2014). Therefore, the returns from an enterprise and their impact on the total production cost are determined. Another advantage of enterprise budget analysis is to determine the potential profit. This is attained when the revenue from the sale of products is higher than the total of all costs associated with the system. Accordingly, positive returns of an enterprise indicate that it would be profitable, and the opposite is true (Engle & Neira, 2005; Fern, 2014).

2.2 Enterprise Budget Analysis- A Review

The enterprise budget analysis was developed for a greenhouse system in Alabama, which contains integrated tilapia and cucumber (Fern, 2014). The system produced 23,940 lb of tilapia and 47,779 lb of cucumbers per annum. Moreover, the annual net return of tilapia and cucumbers were $50,274 and $47,779 respectively. The breakeven price for a pound of tilapia was $1.16 to cover the operation cost, with an extra $0.39 for each pound to cover the fixed cost. On the other hand, the breakeven price for a pound of cucumber was $0.25 to cover the operation cost, with an extra $0.11 for each pound to cover the fixed cost. For the fish component of the system, 64% of the operational cost was for the feeding and fingerlings. For the cucumber component of the system, the majority of the operational cost accounted for the heating of the greenhouse. The labour, land and construction costs were excluded from this budget analysis.

Fern (2014) compared the economic expenses and returns of three exhaustive fish production systems which are: indoor recirculating tilapia system in Auburn, integrated tilapia/cucumber greenhouse system in Browns and catfish floating in-pond raceway system in Alabama. The economic feasibility of each system was developed through the enterprise budget analysis. About catfish floating in-pond raceway system, in scenario one production of mixed catfish species offered net return which was above variable cost $13,681, and the return beyond the variable cost was -$1,841.

In scenario 2, hybrid catfish production accounted higher income than variable cost which was $9,157 and -$6,365 return beyond the variable cost. In scenario 3, production of channel catfish had a net return beyond the variable and total cost of $18,205 and $2,684, respectively. 92% of variable cost accounted for fingerlings, feed and energy for aeration. While fingerling cost was the primary variable cost in all three scenarios. Notice that scenario 3 had a positive net return for both total and variable costs. While both scenarios 1 and two had gained more favourable returns than the variable cost, this indicates that it has potential short-term profitability. The least profitable among the three scenarios in the long term was scenario two because of the highest feed and hybrid fingerling cost.

Economic analysis for commercial aquaponics system in Arkansas was carried out by (English, 2015). In this study, the author developed an individual enterprise budget for three scenarios that produce: tilapia and basil, tilapia and lettuce and all tilapia, lettuce and basil. Associated cost and revenues were calculated using cost and revenues analysis. Tilapia production in aquaponics system resulted in unprofitable in Arkansas. The negative net return was $23,020. High fingerlings and cost of feed can make up for the loss of revenues related to the production of tilapia as well as the relatively low market prices. In the hydrodynamic fragment, the lettuce production was found profitable, and the expected annual net returns were $57,025.

In this system, the high amounts of production have offset these costs, giving a net profit in lettuce production. For the production of basil, the enterprise budget showed a high potential profit with a net return of $215,753 per annum. This interestingly substantial return is because of the high production values and the favourable marketability of fresh basil. Chen *et al.* (2017) constructed an enterprise budget for a model oyster (*C. gigas*) farm operating at a traditional Hawaiian fishpond on the island of O‘ahu. In this budget, the annual projected farm output was 156,000 market size oysters. The total annual cost accounted $204,470. It was estimated that net negative returns of −$9,469 at a selling price of $1.25 per oyster. The highest operational costs accounted for labour and oyster seed which comprised 64.1% and 10.9% of the overall budget, respectively. Therefore, the study concluded that small-scale oyster farm appears to be marginally unprofitable. However, they suggested that oyster enterprise may be economically viable with increasing production, maintain low mortality rate and high selling price.

2.3 Aquaponics- A Review

Aquaponics is an ecosystem that integrates the techniques of aquaculture and hydroponics in a recirculated manner, to produce both fish and vegetables concurrently. In other words, it syndicates fish and hydroponically plants production via symbiotically jointly, closed eco-culture (Al Hafedh *et al.* 2008; Graber & Junge, 2009; Endut *et al.*, 2010). Due to that, aquaponic systems became ecologically sound, bio-integrated, productive, and sustainable technique for food production (Al Hafedh *et al.*, 2008). Such systems are employed in the production of green vegetables, other vegetables, flowers and diverse fish kinds (Diver, 2006; Al Hafedh *et al.* 2008). This system is designed so that the waste generated from a biological system (i.e. fish) is used as a nutrient for the other biological system (i.e. the plant) (Diver, 2006).

The aquaponic system is the water that is rich in nutrients circulated from the tank hosting fish to the beds were vegetable is planted. The fish effluent from the tank serves as fertilizer to the grown plants. It composed of fish manure, decomposing fish feed and algae. Aquaculture effluent contains nutrients such as ammonia, nitrate, nitrite, phosphorus, potassium, and other secondary, micronutrients, dissolved solids and waste by-products. Plants act as a filter by absorbing the nutrients, purifying the water and circulated back to the fish tank. Fish is benefited as plant roots and rhizobacteria removing nutrients from the water (Diver 2006; Al Hafedh *et al*., 2008).

The nitrifying rhizobacteria which are living in the gravel, and in association with the plant roots are vital to functioning the whole system through nutrient cycling. Nutrients in fish waste serve as a food source for nitrifying bacteria. They convert the toxic waste into more readily available nutrients for the plant's uptake (Diver, 2006; Al Hafedh *et al*., 2008). These nutrients have been proven to be much better and more effective organic fertiliser for plants compared to chemical fertilisers. Thus, the hydroponic plant beds important as a biofilter or natural filter. Ammonia, which is toxic to the fish, is broken down by *Nitrosomas* sp. bacteria into nitrite through the process of nitrification. Nitrite, which is also toxic to fish is then converted into nitrate by *Nitrobacter* sp. Nitrate is much less toxic to fish, and it is the form of nitrogen that plants absorb. Nitrifying bacteria and nitrification are crucial for successful aquaponic production (McMurty *et al*., 1997).

The aquaponics system is defined to be intensive for plant and fish production, as it facilitates the operational setting for the recirculation of water between the fragments of the system, i.e. plant growing and fish farming. As the cultivation of plant is performed in the hydroponic system, the vegetable produced show higher standard of commercial quality than conservative vegetable cultivation in an open field (Dediu *et al.*, 2012). Also, an in the aquaponic system's water is used to produce the same amount of fish and vegetables than the water used in conventional practices (Al Hafedh *et al*., 2008).

2.3.1 Aquaponics- Historical Development

The history of aquaponics systems can be long back to ancient times. There were two independent systems namely, fish farming and hydroponics. These two systems were combined to integrate aquaculture with the hydroponic production of plants since the last few decades of the century (Fox *et al*., 2010).

The practice of aquaponics was established long ago and has been in practice for hundreds of years. The Aztec agricultural islands system was one of the earliest, it is known as ‘chinampas’ which are the “floating gardens” that float on top of shallow lakes about 1,000 years ago to the present found in Myanmar and Bangladesh (Crossley, 2004). Furthermore, integrated systems where fish, ducks, pigs, chicken, and plants (e.g. flood rice) were grown in ponds are known since ancient times in Asia. In areas like South China, Thailand and Indonesia fishes have grown in rice fields 1,500 years ago (Coche, 1967). This practice of polyculture is of the present today, knowing that hundreds of thousands of rice field hectares are still stocked with fish. In integrated systems with polyculture, animal stables were built over the ponds for the animal faeces to be on the pond to fertilise algae eaten by fish, and the crops that grew in it (Coche, 1967).

Research on combined aquaculture with hydroponics started in the early 1970s which at first involved experiments on different fishes and plants with different systems and experimental conventions (Rakocy & Hargreaves, 1993). In 1980, a significant revolution was attained by introducing aquaponics, which is an attractive method in food production that utilises only a minimum amount of fresh water resources (Diver, 2006; Al Hafedh *et al*., 2008). A research team at the University of the Virgin Islands (UVI) developed an aquaponic system in 1980 that produced tilapia, ornamental fish, aquatic plants and edible plants.

The aquaponic researchers developed a small system at first and then expanded that small-scale system into a commercial system, which holds six hydroponic tanks with a growing area of 2,303 ft^2 and four fish rearing tanks are containing 7798 litres of water each (Rakocy, 2012). This aquaponic design is one of the critical innovation in the aquaponics industry. McMurthy *et al*., (1993; 1997) introduced in 1986 the first closed-loop aquaponic system termed “an aqua-vegeculture system”, which used tilapia effluent into sand-planted tomato beds. As water drains from the sand grow beds, it was recirculated back into the fish tanks. The most recent developments in the system have also come from the University of North Carolina by some researchers (Fox *et al*., 2010).

2.3.2 Aquaponics in the Arabian Peninsula

The Arabian Peninsula is one of the semi-arid regions of the world. It has low rainfall and extremely high evaporation rates and temperatures. Plant cultivation relies on the input of high amounts of irrigation water. Additionally, the region also has minimal fresh water resources (Nichols, 2015). These resources are also on a continuous decline, and the governments of these countries are supporting the development of farming systems with high water use efficiency, to reduce or minimise water wastage. In the UAE, the surface water resources are almost non-existent, while the groundwater sources are also very few and most are non-renewable (Mazahreh *et al*., 2015).

Desalinated seawater is the primary source of potable water in the UAE. Also, the country is also making use of sewage water by recycling to bring it back to the quality that is approved by World Health Organization as potable water (Nichols, 2015). Similarly, in Saudi Arabia and other GCC countries, there are freshwater shortages, and fresh water becomes a scarce commodity. Even though the water resources are limited, the development of aquaponics and freshwater aquaculture adoption are very slow in the region. However, it is being supported by the governments in these countries to use the latest techniques that maximize water reuse as well as strengthen fish culture (Al Hafedh *et al*., 2008; McMurtry *et al*., 1997; Simeonidou *et al*., 2012) stated that aquaponics could be utilized as a strategy or framework to diminish water necessities, fish and vegetables can be created in commonly advantage water reuse.

The hydroponic systems could utilise the reused or desalinated water from the ocean for vegetable production and create farming in the nation. Nursery hydroponics are at present advanced in the UAE. Mostly leafy vegetables are being developed utilising hydroponic frameworks under controlled conditions. The Zayed Higher Agricultural Centre for Development and Rehabilitation in Abu Dhabi was formed in 2011, which is the largest aquaponic centre in the world. In the very first year of operations, the centre produced 10 tonnes of fish and 60,000 tonnes of Lettuce (Malek, 2012).

The project currently produces 25 tons of tilapia fish and around 400,000 head of lettuce annually. The Baniyas centre has a target of producing 300,000 heads of lettuce and 200 tonnes of fish every year (Malek, 2012). There is a proposed aquaponic system in Al-Khatim in Abu Dhabi. This design will include the production of tilapia and barramundi at intensive stocking densities, whereas the hydroponic system will produce leafy vegetables.

2.4 Hydroponics and Aquaculture- A Comparison

Hydroponics is defined as the production of vegetations without soil. In this system, nutrient solutions, mainly synthetic chemical fertilisers that consist some indispensable elements for the growth of the plant and development are supplied on a periodical cycle to the crop through irrigation water. There are several liquid hydroponic systems that include the nutrient film technique (NFT), floating rafts, and noncirculating water culture (Gonzales, 2002). In aggregate hydroponic systems, a solid, inert, medium such as sand, sand, vermiculite, perlite, gravel, coconut coir which contained in bag, trench, trough, pipe, or bench setups are used to provide support to the plant (Diver, 2006). For instance, sand growing beds were used by (McMurtry *et al.*, 1990; Rakocy & Nair, 1987) used loose sheets of polystyrene to support the plant. Lennard and Leonard (2006) compared NFT, gravel beds, and floating rafts in aquaponics to produce lettuce. Hydroponic systems are usually operated in a facility with a controlled environment that would help to increase the yield of the crops.

Aquaculture or aquafarming, is "*the breeding, rearing and harvesting of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants*". The recirculating aquaculture systems (RAS) are the most efficient, water-saving and popular technology nowadays that is used in fish farming. Also, it offers a more significant advantage in optimising productivity and giving high-quality market products. In this system fish tank effluent is cleansed by recirculating through a system of filters. However, RAS is expensive and require skilled persons to operate.

2.4.1 Plants Adapted to Aquaponics

Green vegetables and harvests that usually consumed as a part of aquaponics are water spinach, spinach, lettuce, tomato, cucumber and pepper (Alder *et al*., 2000). Plants that adapt to the hydroponic cultures in an aquaponic system are selected based on the stocking density of the tanks hosting fish and the concentration of the nutrient from the effluent of the aquaculture (Blidariu and Grozea, 2011). Herbs, lettuce and speciality greens (e.g. chives, spinach, watercress, and basil, rosemary, sage, parsley and mint) are characterised by frequent requirements of nutrients and are suitable for aquaponic systems. Other plants that yield to fruit (e.g. tomatoes, cucumbers, peas, bell peppers and squash) have a higher demand of nutrients and respond appropriately to the well-established aquaponic systems (Diver, 2006; Rakocy *et al*., 2006).

Lettuce is a prominent vegetable crop that grows in aquaponic systems. It has heritably diverse shapes, colours and textures. Lettuce proliferates, reach to harvestable plant age relatively quickly. Also, it is consumed slowly throughout the world (Lennard and Leonard, 2006). Lettuce can be harvested within four to five weeks (Rakocy *et al*., 2006). Moreover, a high proportion of the harvested biomass is edible, unlike tomato and cucumber (Rakocy and Hargreaves, 1993).

2.4.2 Fish Species in Aquaponics

Aquaponic systems successfully raising various types of fish species including several varieties and hybrids of tilapia such as Nile tilapia (*Oreochromis niloticus*), red tilapia, hybrid tilapia, (*Oreochromis urolepis hornorum* x *Oreochromis mosambicus*), and several other fish species such as koi carp (*Cyprinus carpio*), hybrid carp (*Ctenopharyngodon idella* x *Aristichthys nobilis*), hybrid striped bass (*Morone chrysops* x *Morone saxatilis*) (Selock, 2003), goldfish (*Carassius* sp.), rainbow trout (*Oncorhynchus mykiss*) (Adler *et al*., 2000), Australian barramundi (*Lates calcarifer*), arctic char (*Salvelinus alpinus*), and murray cod (*Maccullochella peelii peelii*), and various crustaceans such as red claw crayfish (*Cherax quadricarinatus*), louisiana crayfish (*Procambarus clarkii*), and giant freshwater prawn (*Macrobrachium rosenbergii*) have also been grown in aquaponic systems (Rakocy *et al*., 2006; Diver, 2006; Nelson, 2009; Hollmann, 2013).

Tilapia (*Oreochromis niloticus*) is the most commonly used fish in aquaponics systems and is the favoured species for tropical and sub-tropical regions of the world (Rakocy *et al*., 2004; 2006; Yue and Zhou, 2008). Tilapia is a warm water species that produces white-fleshed meat (Diver, 2006). High availability, easy to breed, ability to grow and reproduce in a wide range of environmental conditions, easy to adopt indoor environment and fast growing are the most likely factors that make tilapia species ideal for use in aquaponics systems. Also, they also exhibit several feeding regimes, consuming bacteria, diatom-rich sediments, particulate detritus, phytoplankton, zooplankton, benthic organisms, insects and fish (Bowen & Allanson, 1982; Maitipe & de Silva, 1985). Moreover, they can tolerate fluctuating water conditions such as pH, temperature, oxygen and dissolved solids, and also it tolerates stress by handling (Yue and Zhou, 2008), and has high resistant to diseases (Hussain, 2004; Diver,2006; Tsadik & Bart, 2007). It can be produced in extensive, semi-intensive and intensive culture systems.

Tilapia experiencing stress at low Dissolved Oxygen, high total nitrate levels, high total ammonia nitrogen levels and low pH levels. The ideal growing conditions for this species, as most others, lean towards a higher DO than 6ppm, higher pH levels than 6, and low ammonia and nitrite levels. Catfish (e.g. *Clarias gariepinus*) is tolerant to low oxygen and high nutrient contents, and common carp (*Cyprinus carpio*) can be cultured at high density and much colder waters than most tilapia species. Although their feeding regimes are not as broad, their water quality tolerances are similar to or exceed those of many tilapia species (Jingbo *et al*., 1994).

2.5 Aquaponic System Designs

There are many aquaponic setups used in worldwide. Most of these setups constructions are based on three main types of aquaponic systems: media-based growing (or grow beds filled with media), deep-water culture (DWC) or floating rafts, and nutrient film technique (NFT). Aquaponic systems have three main components including the aquaculture unit, the hydroponics unit and the intermediate or filter unit. The essential elements of an aquaponic system include: a tank to rear fish; a clarifier to remove suspended solids such as small particles which originated from fish waste, algae, and uneaten food; a biofilter which is the substrate for adhesion of nitrify bacteria, and oxygenation; a hydroponic plant growing beds and a sump pump (Rakocy & Hargreaves 1993; Rivara, 2000; Lennard & Leonard 2006).

In the media-based method, plants are grown in large containers which filled with media (gravel and perlite) and water from the fish tank is pumped to these containers. There are an essential flood and drain systems, designs with sump tanks, constant height one pump systems, and even systems using barrels (Bernstein, 2011; Lennard & Leonard, 2006). In this system, seeds can be planted directly into the media, or transplanted from nurseries.

The media provides several benefits including serving as an efficient solids filter, providing ideal growth environments for beneficial bacteria, and thereby ensuring biofiltration and nitrification to make the water reusable for the fish. Also, provide support for the plants, ensure supply of nutrients and oxygen to plants, nutrients to be accessible to plant roots. However, this system is more appropriate for small-scale as it does not produce a maximum plant production. NFT and DWC is mostly used for commercial scale, and they produce at a faster rate.

NFT uses the more similar technique to hydroponics. A shallow stream of water is recirculated in horizontal pipes into the root system of the plants. This water contains all the dissolved nutrients for plant growth. Plants are grown in small pots filled with media that are inserted in holes in the gutters (long tubes or channels). NFT is more suit for shallow roots plants such as herbs and lettuce, than the plants with more massive root systems that can be clogged the channels (Love *et al*., 2015).

DWC system which is also known as floating rafts system. In this system plant, roots are suspended directly into large water-filled beds or troughs in on floating rafts.

Floating rafts which support the shoots above the waterline, as the roots hang into the water. An air pump supplied air from the bottom of the raft at regular intervals for oxygenating and kept the roots from drowning. This system is the most common and promising for large commercial aquaponics. Also, it is a more straightforward setup, relatively inexpensive, more comfortable to construct, low maintenance cost; crops are easy to harvest and reliable. The aquaponic system has been pioneering in this technique for many years.

2.5.1 The University of Virgin Islands (UVI) System

There are several aquaponic models used in the world including the systems developed by the North Carolina State University, the University of the Virgin Islands (e.g., the Speraneo system), the Freshwater Institute, the Cabbage Hill Farm, and the New Alchemy Institute (Diver, 2006).

The research team of James Rakocy (the University of the Virgin Islands) led to developing the first aquaponic system, which could be applied either outdoors under suitable growing conditions or in an environmentally controlled greenhouse (Rakocy *et al*. 2006). This system has been produced tilapia and diverse types of vegetables, such as basil, lettuce, and okra with outstanding quality and yield. Thus, this is considered as a successful design model for the aquaponic industry. The UVI system can be produced 5MT of tilapia annually under optimum temperatures and feeding management. Production averages 580 kg of tilapia every six weeks and 160 kg/m^3/year of rearing tank space. The system can produce 1,400 cases of lettuce (24-30 heads/case) or 5MT of basil or 2.9MT of okra pods (Rakocy *et al.*, 2006).

The system consists of four aquaculture tanks (7.8 m^3 each), two clarifiers, four filter tanks and one degassing tank, air diffusers, one sump, one base addition tank, pipes and pumps, and six hydroponic troughs (11.3 m^3 each) (Figure 1). The total water volume and hydroponic tank growing area are 110 m^3 and 214 m^2 respectively (Rakocy *et al*., 2006). In this system, water from the aquaculture tank goes through sump, clarifier and degassing tanks that remove most of the solids from the fish waste. The aquaculture effluent is linked to floating raft hydroponics. The water is pumped into six hydroponic tanks that are fed by effluent lines. Hydroponically grown crops take nutrients from the water and purify and then recirculate back the fish tank.

The treatment processes consist of aeration, solids removal, denitrification, decomposition, degassing, nitrification and direct uptake of ammonia and other nutrients by plants. The fish are fed *ad libitum* three times daily with floating pellets. Biological methods control plant pests and diseases. pH is monitored daily and maintained around 7.0 by alternately adding equal amounts of calcium hydroxide and potassium hydroxide (Rakocy *et al*., 2006).

The UVI system is simple, reliable, and robust and represents an appropriate or intermediate technology. Simultaneously, it provides several substantial benefits. It is able to give continuous production of plants and fish and requires less land area. Also, it conserves and reuses water, and recycles nutrients. Thus, production is sustainable. However, the UVI system requires high capital investment, reduced energy inputs and skilled management, as illustrated in Figure 1 (Rakocy *et al*., 2006).

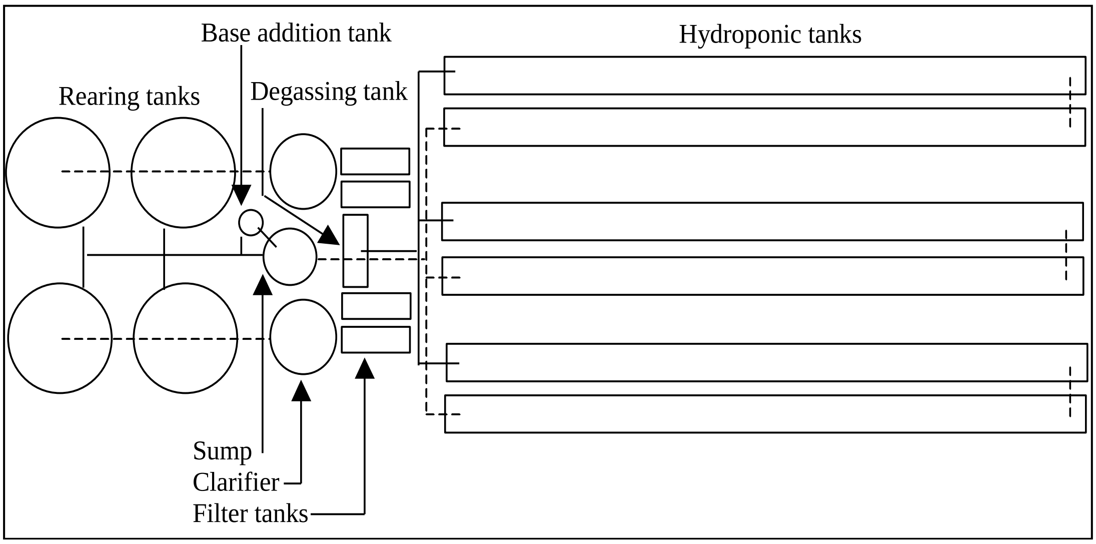

Figure 1: Aquaponic system
(Rakocy et al, 2006)

Figure 2: Basil production in the UVI aquaponic system
(Rakocy *et al*., 2006)

2.5.2 Importance of Aquaponic Systems

Aquaponic systems integrate aquaculture and hydroponics in a recirculating engineered ecosystem to simultaneously produce fish and different vegetables. Since an integrated system, aquaponics provides various environmental and economic benefits than working as two separate systems; non-recirculating aquaculture systems and hydroponic systems that use chemical nutrient solutions. The study by (Adler *et al.*, 2000) has also revealed that the hydroponic component provides potential profitability as a part of the integrated system, which gives significant annual returns from plant production. Also, aquaponics has great importance regarding maximising the food production (Mateus, 2009).

Aquaponics is an efficient, cost-effective, and water saving technology that consume less water while reusing (McMurtry *et al*., 1997). The system is continuously recirculating nutrient-rich water. Thus, extra water needs to be added only to compensate for evaporation. The hydroponic systems need more water and should maintain high water quality. In fact, aquaponic systems do not require such higher water quality. Moreover, there is no toxic runoff to the environment. The effluent from fish tank contains phosphates and nitrates which would typically be discharged to the environment and could contribute to pollution (McMurtry *et al*., 1997; Al-Hafedh *et al*. 2003; Rakocy *et al*. 2004). Removal of nutrients by plants prolongs water use and provide several environmental benefits. The system does not encourage the over nourishment of water resources due to nutrients, which can cause adverse effects including eutrophication with algal blooms (Endut *et al*., 2010).

The aquaponics; however, does not need soil. Therefore, marginal land can be utilised to produce fish and vegetables. These systems are the commercially viable solution for water scarce arid regions. Growing plants in containers filled with different non-soil media and using direct nutrient application can eradicate soil-borne pests, diseases and weeds. The hydroponic unit serves as a biofilter (Mateus, 2009); therefore, a separate biofilter is not required. Aquaponic systems can increase local availability of a variety of vegetables and fish throughout the year. No pesticides, herbicides or antibiotics are used at any stage in the aquaponic production system (Rakocy, 1999). Thus, it can be considered as a part of the organic agriculture. Also, aquaponic systems are leading for water, gas, energy and land conservation. Consequently, the aquaponic systems increase profit potential through cut off chemical fertiliser costs and shared costs for operation and infrastructure (Rakocy, 1999). However, high investment and operation costs are the significant constraints for the adoption of this system in developing countries (Rakocy & Bailey, 2003).

2.5.3 Aquaponic Feeding Rate Ratios

Aquaponic fish to plant ratios or aquaponic feeding rate ratios is the most critical factor in the designing of an aquaponic system (Rakocy, 2007; Lennard, 2012). There are many approaches to size the two major components in the system (the fish and the plant components) either small-scale context or commercial scale context. However, there are two scientifically based approaches: The Rakocy approach and the Aquaponic Solutions/Lennard approach (Lennard, 2012).

In the aquaponic system, the fish are fed, the fish produce wastes and this waste is utilised by the plants as a nutrient for their growth. Therefore, the amount of waste produced is in direct proportion to the amount of fish food consumed by the fish. The amount of plants that can be grown is proportional to the number of nutrients available which in turn depends on the amount of waste produced by the fish. This, in turn, depends on how much food is fed to the fish (Lennard, 2012).

Lastly, the only predictable direct association between 2 major components of the aquaponic system is based on the amount of fish feed that enters the system and the number of plants we grow (Rakocy, 2007; Lennard, 2012). Accordingly, to size the aquaponic system or to calculate the feeding rate ratio should determine, how many plants and of what species would like to produce, how much area the plants need to grow, how much fish feed, the fish need to eat to meet the nutrients for those plants, the weight of fish are required to eat that much fish food, what volume of water that amount of fish need to rear (Lennard, 2012).

2.5.4 The Rakocy Approach

James Rakocy and the team at the University of the Virgin Islands were the first to develop scientifically proven and predictable approach to aquaponic feeding rate ratios. Accordingly, for a raft hydroponic system, the optimum ratio varies from 60 to 100 g/m^2 /day, and for the nutrient film technique hydroponic system it is approximately 25% of the ratio used for a raft system (Rakocy, 2007).

For example, if the fish are being fed 1,000 g per day on average, the area devoted to hydroponics production should be $16.7m^2$ for a feeding rate ratio of 60 g/m^2 /day. Conversely, if 200 m^2 are devoted to plant production, then the fish tanks, tank volumes, fish stocking rates, and production schedules should be manipulated in such a way as to achieve average daily feed input to the system of 20,000 g (44 lbs) if a feeding rate ratio of 100 g/m^2 /day is desired (Rakocy, 2007). Also, (Rakocy *et al.*, 2006) pointed out that the rate of change in nutrient concentration can be influenced by varying the ratio of plants to fish. (Al-Hafedh *et al.*, 2008) used a ratio of 56 g fish feed m^{-2} in their study as the efficient feeding rate ratio.

2.5.5 Stocking Density and Feeding Frequency

Nutrients dynamics are quite sophisticated in an aquaponics system (Seawright *et al.*, 1998). In such system, the feed is the primary source of nutrients which are eventually tied up as the biomass of animal, plant and microbes or stayed free in the water. When no discharge, no nutrients are output until the animal and plant are harvested as commercial crops. Through microbial decomposition, the insoluble fish metabolite and unconsumed feed are converted into soluble nutrients which then can be absorbed by the plant. Therefore, plant growth and production are indirectly related to feeding strategies, fish metabolic condition and microbial activity. While plant removes the soluble nutrients, water is filtered. Consequently, the nutrient availability for plant and fish, and thereby water quality or fish growth and production highly depends on the ability of nutrient uptake by the plant (Liang and Chien, 2013). In addition to those factors system designs, plant and fish species and other physical factors such as temperature, light sources and photoperiod also impact it (Gopal, 1987; Urbanc-Bercic and Gaberscik, 1989).

The stocking density of fish in the aquaponic system is essential for the proper functioning of the system. It is essential to maintain optimum stocking densities with other factors in the aquaponics systems, since it effects on the water quality, and consequently the production of plant and fish. Also, it leads to higher growth rate, the yield of fish, and in turns provides higher economic benefits from the system (Shoko, 2016). Good water quality conditions allow higher stocking densities. Tilapia can be cultured at high densities in floating cages wherein large lakes and reservoirs which practised in China, Indonesia, Mexico, Honduras, Colombia, and Brazil to achieve higher productivity (FAO, 2018). However, high stocking densities could adversely impact on feeding, growth, and other physiological processes of fish (Wedemeyer, 1997). For instance, high stocking densities can cause intraspecific competition for sharing space and feed. It also resulted in declining of water quality conditions and uneven food distribution. Consequently, high density leads to stressful condition for fish (Houlihan *et al.*, 2001).

Feeding frequency can affect feed intake of fish, the quantity of uneaten feed, feed utilisation efficiency, and consequently, metabolite and excreta of fish and water quality. In an intensive culture of fingerling walleye *Stizostedion vitreum*, (Phillips *et al.*, 1998) found that higher frequency feeding resulted in higher daily dissolved oxygen (DO) and lower total ammonia nitrogen in the system. Postlarval Ayu *Plecoglossus altivelis* with higher feeding frequency at lower feeding rate had higher survival and growth (Cho *et al*., 2003). When fed at 10% body weight daily, newly weaned Australian snapper *Pagrus auratus* fed eight times a day had higher growth and lower size heterogeneity than fed 4 and two times a day (Tucker *et al*., 2006).

The feeding rate of an aquaculture system relies on the stocking fish density, feeding frequency, feeding practices, the health of the fish, size of the fish and feed pellet. In addition to these factors, it depends on water temperature, water quality and the specific objectives of the aquaculture production system (Wellborn, 1989; Hargreaves & Tucker, 2003). The amount of feed supplied to the tank is related to the density of the fish. More feed is needed for higher stocking densities of fish than at lower densities. The size of fish affects food consumption. Because small fish require more food about body weight, and more abundant fish need a higher overall quantity of food. Moreover, feed distribution should be properly done by considering sufficient time and space for fish to consume all the feed, and in turns attain adequate growth while minimising feed waste (Cho & Bureau, 2001).

Chapter 3: Materials and Methods

3.1 System Description

This section provides descriptive illustration and outline of the aquaponic system used in the experimental part of this thesis. The dimensions of the insides Aquaponic units inside was 400 m^2 greenhouse with a 120 m^2 plantation area in four turfs (each 24.4* 1.23* 0.42 m^3 L W H covered with 2-inch-thick perforated Styrofoam sheets), two circulars (3m diameter and 1.2 m high) fish tanks each with 7.7 m^2. The fish tanks connected to water treatment units include circular with cone shape bottom (2 m^2 diameter with water volume of 4.5 m^3) swirl separator for mechanical filtration connected to U-tube to remove sludge by siphoning followed by two connected biological filters for nitrification, (1.8*80*0.6 m^3 each) tanks one third filled (35 kg) with plastic media (HDPE polymer with very high surface area; 899 m^2/m^3) from Pentair's Sweetwater (USA).

Water from the biological filters moves to a CO_2 stripping tank (1*0.6*0.6 m^3) before moving to the four plantation raceways. Water moves in the system at a rate of 10 m^3L/hour from fish tanks to the water treatment system and plantation raceways by gravity and returns to fish tanks using 3 Hp water tanks. Total water volume 58 m^3. The system was aerated by an air blower (S53-AQ Sweetwater Regenerative Blower 2.5 HP (MFD; Aquatic Eco-Systems, INC Apopka, Florida USA) through one-inch PVC pipe and a rubber houses. Each fish tank has 20 silicon air stones (each 20 cm length), and each water trough has ten air stones (each 10 cm in length). Water consumption from evaporation and evapotranspiration and cooling system were measured using two water meters (KENT PSM 15 mm water meter PN 16, GRUNDFOS, England. Electricity consumption was measured using one electrical meter (Elster A1100 polyphase meter by Elster metering Ltd. Stafford). One air cooler fan: Euroemme® EM50n, exhaust fan with 1.5 HP motor. (fan) Propeller diameter 1,270 mm. 6 Kista, blade, Sweden. One WATER PUMP for cooling pad: GRUNDFOS *DK-8850*, 1 HP single phase motor capacity of water pulling five m^3/h. Figure 3 outlines the core components of the experimental aquaponic system.

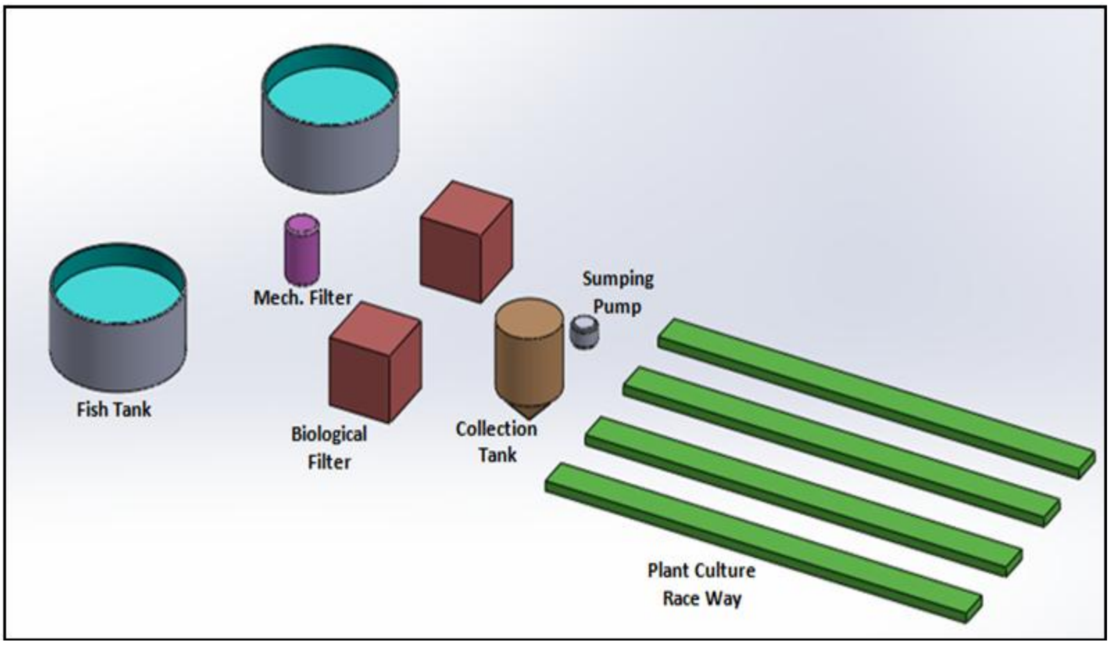

Figure 3: Components of the experimental aquaponic system

3.2 Fish Introduction and Acclimatization in Aquaponic Tank

Before starting the experiment, the whole aquaponics system was cleaned thoroughly and kept dry for one month. After that, tap water was introduced in full aquaponics system. The initial water quality parameters were analysed, and water was circulated in the closed condition of the aquaponics system for one week before introducing fish to the system. Then a sample of water was drained to analyse its quality to confirm that it meets the standard aquaponic water quality parameter; otherwise, the water parameters should be adjusted to the desired level that allows substantial growth of fish and lettuce.

Then, the selected Tilapia (*Oreochromis niloticus*) fish, fingerlings (approximately 5 to 8cm length and 5 – 10 gm weight) was introduced into the stocking tank of the greenhouse and acclimatised for one week under greenhouse conditions. At the beginning of the period of acclimatisation, specifically in the first two days, the fingerlings are starved to reduce the stress from the new environment. Then, the fishes were fed using a commercial feed (32% of Crude protein) purchased from ARASCO Feeds from Saudi Arabia. The fishes were fed once, twice or three times a day with the ratio of 5% of the total weight of the fish in the tanks.

After seven days of the fish acclimatisation, the Lettuce seeding started in cultivation area. The seeds are germinated directly in the same aquaponics water condition. Seeds can be transferred in a cleaned plastic cup of rock wool substrate. The seeds contained rock wool cups that are directly inserted in the stay foam sheet in the plant cultivating raceway of the aquaponic system.

The aquaponic system environment is controlled by pests and ants. Also, the sticky papers are hanged in the surroundings of the plant cultivating areas to catch the fly pests. After the germination started, the growth parameters were marked once every ten days, while the fishes were counted and weighted two months once. Water quality and light intensity were monitored once every week. Also water chemistry was analysed twice a month.

3.2.1 Experiment 1- Feeding Frequency

Fish tanks were stocked with 100 fish/m^3 of *Oreochromis niloticus*; fingerling was achieved with an average weight of 5 g. Nile tilapias were fed while floating with a commercial feed of 36% protein from Arabian Agricultural Services Company ARASCO, Saudi Arabia. This experiment was conducted in three aquaponic systems; The acclimatised fishes were fed with floating feed in aquaponics system with feeding frequencies of 1 time per day, two times per day and three times per day. The experiment was performed for a period of three months with a replicated study. At the end of the experiment day the tilapia growth and growth parameters namely; fish weight gain (WG), feed intake (FI) and feed conversion ratio (FCR). Additionally, protein and fat deposition values were calculated using the following equations:

$$\mathrm{WG} = \mathrm{W}_1 - \mathrm{W}_2 \qquad (1)$$

$$\mathrm{FCR} = \frac{\mathrm{FI}_{\mathrm{dry}}}{\mathrm{WG}} \qquad (2)$$

Where, W_1 and W_2 are the mean initial and final weight in grams, respectively.

Raceways were planted in Styrofoam at a rate of 24 lettuce (*Lactuca Sativa*) seeds per square meter. Lettuce seeds were inserted through a piece 1-inch Rockwool cube, 2-inch length inside a perforated bottom plastic cub. Lettuce was harvested every 30 days, and a new seed was planted to start a new crop. Lettuce characteristics of each harvest were evaluated by measuring Length (green to root), green length, root length, total weight, green weight (head), leaf weight, leaf length, leaf width, and an average number of leaves.

Sludge was collected daily by syphoning from the swirl separator in a plastic bucket in the left to settle the solids for one hour. Then, it was transferred to 2 m^2 tray open to air for drying. Floating sludge was collected using fine net three times a day, and then placed try above a dry.

3.2.2 Experiment 2- Fish Stocking Density

Fish tanks were stocked with 100 fish/m^3, 120 fish/m^3 and 140 fish/$m^{-\ 3}$ of *Oreochromis niloticus* fingerlings are introduced in aquaponics system one, two and three respectively with an average weight of 15-20g. The Nile tilapias were fed while floating with a commercial feed of 36% protein from Arabian Agricultural Services Company ARASCO, Saudi Arabia. The experiment was performed for a period of three months with a replicated study at the end of the experiment day the tilapia growth and growth parameters namely; fish weight gain (WG), feed intake (FI), and feed conversion ratio (FCR). Additionally, protein and fat deposition values were calculated using equations (1) and (2) that were mentioned in the last section.

Raceways were planted in Styrofoam at a rate of 24 lettuce *Lactuca sativa* seeds per square meter. Lettuce seeds were inserted in a piece one-inch Rockwool cube 2-inch length inside a perforated bottom plastic cub. Lettuce was harvested every 30 days, and new seeds were planted to start a new crop. Lettuce characteristics of each harvest were evaluated by measuring Length (green to root), green length, root length, total weight, green weight (head), leaf weight, leaf length, leaf width, and an average number of leaves.

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3.3 Analyses

The LUX meter (Make: Takemura; Model: DM-28) measured the light intensity weekly, whereas, analysing the water quality after treatment from tanks weekly. pH, Temperature and Electrical conductivity was measured using HACH HQd portable meter (Make: HACH; Model: HQ 40d), TDS (HACH TDS meter Pocket pro™ (HACH; Model: DR 900), TAN (Total Ammonia Nitrogen) (Salicylate method) Nitrite (USEPA Diazotization Method), Nitrate (Cadmium Reduction Method) and Fe (FerroVer® Method) using HACH portable calorimeter (HACH; Model: DR 900). DO, Orion star™ and Star plus meter (Make Thermo Scientific; Model: Orion 4 star), Total Alkalinity and acidity were measured by titration method of APHA standard methods 2003, Minerals Analysis was done using ICP-OES. (Inductively Coupled Plasma Optic Emission Spectroscopy (ICP_OES) Model 710- ES, Varian, United States).

Experimental diet and fish, lettuce and sludge samples were analysed in triplicate for moisture using a forced air oven, crude protein by macro-Kjeldahl, crude fat by ether extraction method total ash by muffle furnace (550 ^{o}C) for 24 h, and CF (for feed samples only) using Lab. Conco (Lab. Conco Corporation, Kansas City, MO, USA). The methods of approximate analysis were performed as described in AOAC (1990). Growth energy was calculated based on standard energetic values for protein (23.67 MJ kg), carbohydrate (17.17 MJ kg) and lipids (39.79 MJ kg) (NRC 1993).

Figures 4 to 6 illustrating different fragments of the adopted experimental aquaponic system .

Figure 4: The greenhouse hosting the different system fragments

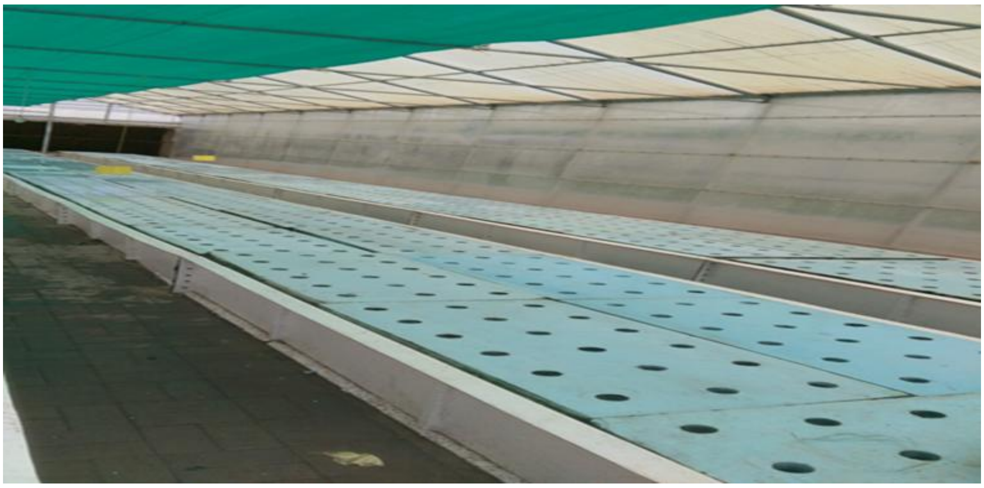

Figure 5: Raceway

Figure 6: Plant culture raceway

The different products from the system, i.e. lettuce and tilapia fish after the experiment period are displayed in Figures 7 and Figure 8, respectively.

Figure 7: Lettuce produced from the system

Figure 8: Fish species used in the system

3.4 Statistical Analysis

All data were subjected to one-way ANOVA to determine significant ($P > 0.05$) differences among the treatment means. Student–Neuman–Keuls multiple range test (Glantz, 1989) was used to distinguish significant differences among treatment means. All statistical analyses were conducted using a system for Windows (version 8.0, SAS Institute, Cary, NC, USA, 1995).

Chapter 4: Results and Discussion

4.1. Experiment Results

4.1.1 Feeding Frequency

The factors that are manipulated by the different feeding frequencies are studied as well; it was observed in the experiment that while fixing initial weight (~50 g/fish) the mortality rate (~2%) were not changed. The final weight, weight gain, feed intake and feed conversion ratio of the fish increased with increasing the feeding frequency. Growth rate, feed utilisation, and feed conversion values for *O. niloticus* (each value is a mean of two observations) are shown in Table 1.

Table 1: Varied feeding frequency analysis of *O. niloticus*

F.F.	Initial Weight (g/fish)	Final Weight (g/fish)	Weight Gain (g/fish)	Feed Intake (g/fish)	FCR* (%)	Mortality (%)
1	50.2 [a]	126.3 [a]	76.0 [a]	69.6 [a]	1.8 [a]	2.2 [a]
2	52.1 [a]	144.5 [b]	93.4 [b]	180.3 [b]	1.9 [b]	2.0 [a]
3	51.7 [a]	168.6 [c]	116.9 [c]	271.1 [c]	2.3 [c]	2.3 [a]

[abc] Values in the same column with superscripts are significantly different ($P < 0.05$).
*FCR, Feed conversion ratio (feed intake/average weight gain per fish)

Another parameter that increased with increasing feeding frequency is the tilapia and lettuce production, that increased fish density. The mutual impact of fish production and lettuce production is shown in Table 2.

Table 2: Fish production and *L. sativa* production

F.F.	No. of fish (fish/m^3)	Fish production (kg/m^3)	No. of lettuce heads (head/m^2)	Lettuce production (kg/m^2)
1	100	7.6 [a]	28	5.7 [a]
2	100	9.3 [a]	28	6.3 [b]
3	100	11.7 [a]	28	8.1 [c]

[abc] Values in the same column with superscripts are significantly different ($P < 0.05$).

The chemical composition of the products (Fish and Lettuce) while varying the feeding frequency were also studied approximate analysis (crude fats, and less moisture was achieved by increasing feeding frequency, while no changes were observed in the crude protein and ash content) of the fish , as shown in Table 3.

Table 3: Tilapia *O. Niloticus* approximate composition

F.F.	Moisture	Ash (DM)	Crude Protein (DM)	Crude Fat (DM)
1	75.68 [a]	13 [a]	57.5 [a]	30.1 [a]
2	73.84 [a]	13.0 [a]	54.4 [b]	32.4 [b]
3	72.2 [a]	12.8 [a]	51.3 [c]	35.6 [c]

[abc] Values in the same column with superscripts are significantly different ($P < 0.05$)
Body composition expressed as a percentage of dry fish weight

L. sativa composition was not affected by the feeding frequency, as shown in Table 4.

Table 4: Lettuce *L. sativa* head approximate composition

F.F.	Moisture (WB)	Crude Protein (DM)	Crude Fat (EE) (DM)	CHO (%)	Crude Fibre (DM)	Ash (DM)	Energy (KJ/g)
1	97.1[a]	27.0 [a]	3.5 [a]	36.1 [a]	14.7 [a]	21.1 [a]	13.1 [a]
2	96.6[a]	24.9 [a]	3.6 [a]	35.9 [a]	13.0 [a]	20.9 [a]	13.5 [a]
3	95.7 [a]	23.2 [a]	3.9 [a]	36.1 [a]	12.8 [a]	22.5 [a]	13.6 [a]

[a]Values in the same column with superscripts are significantly different ($P < 0.05$)
Body composition expressed as a percentage of dry fish weight

Table 5 shows the water quality as affected by the feeding frequency. It was observed that ions of Sodium (Na), Copper (Cu) and Zinc (Zn) were not significantly changed while the other elements increased with increasing feeding frequency.

Table 5: Average of initial/final water mineral content of each treatment in ppm

F.F.	**Ca**	**Na**	**K**	**Mg**	**P**	**S**	**Co**	**Cu**	**Fe**	**Mn**	**Mo**	**Zn**
0	39.8 [a]	0.003[a]	0.01[a]	0.67[a]	1.6 [a]	3.6 [a]	0.01[a]	0.02[a]	44.2[a]	1.0 [a]	3.3 [a]	0.013[a]
1	60.7 [b]	0.004[a]	0.02[b]	0.02[b]	8.2 [b]	8.7 [b]	0.06[b]	0.02[a]	50.8[b]	7.9 [b]	7.3[b]	0.032[a]
2	94.4 [c]	0.003[a]	0.04[c]	0.03[b]	16.8[c]	16.0[c]	0.14[c]	0.02[a]	60.7[c]	14.5[c]	14.8[c]	0.033[a]
3	109.9[d]	0.004[a]	0.05[c]	0.02[b]	40.9[d]	32.3[d]	0.19[d]	0.02[a]	77.8[d]	19.5[d]	41.7[a]	0.031[a]

[abcd] Values in the same column with superscripts are significantly different ($P < 0.05$)

Table 6 shows the performed water quality tests and the effect of feeding frequency on it, water quality parameters changed significantly as feeding frequency increased.

Table 6: Average of water quality parameters of each treatment in two months

F.F.	Dissolved Oxygen (mg/l)	pH	TDS (ppm)	EC (mV)	Ammonia (ppm)	Nitrate (ppm)	Nitrite (ppm)
1	7.3 ^{a}	6.8 ^{a}	370.0 ^{a}	19.9 ^{a}	0.4 ^{a}	6.3 ^{a}	0.2 ^{a}
2	6.1 ^{b}	6.2 ^{b}	639.9 ^{b}	49.4 ^{b}	1.6 ^{b}	14.3 ^{b}	2.2 ^{b}
3	5.9 ^{c}	6.8 ^{c}	837.1 ^{c}	57.7 ^{c}	1.4 ^{c}	15.5 ^{c}	8.3 ^{c}

^{abc} Values in the same column with superscripts are significantly different (P < 0.05)

4.1.2 Stocking Densities

Some factors manipulated by the stocking density were studied as well; it was observed in the experiment that while fixing initial weight (~50g/fish), the mortality rate (~1.8%) did not change significantly. The final weight, weight gain, feed intake and feed conversion ratio of the fish decreased substantially with increasing the stocking density, as shown in Table 7.

Table 7: Growth, feed utilisation and feed conversion values for *O. niloticus*

S.D.	Initial weight (g/fish)	Final weight (g/ fish)	Weight gain (g/fish)	feed intake (g/fish)	FCR (%)	Mortality (%)
100	130.8	234.7 ^{a}	103.9 ^{a}	190.1 ^{a}	1.83 ^{a}	1.8 ^{a}
120	131.2	212.2 ^{b}	81.0 ^{b}	138.5 ^{b}	1.71 ^{b}	1.8 ^{a}
140	129.5	198.3 ^{c}	68.8 ^{c}	104.7 ^{c}	1.52 ^{c}	1.6 ^{a}

^{abc} Values in the same column with superscripts are significantly different (P < 0.05).
*FCR, Feed conversion ratio (feed intake/average weight gain per fish)

Another parameter that increased with increasing stocking density is the tilapia and lettuce production, that increased considerably, as shown in Table 8.

Table 8: Fish production and lettuce production

S.D.	Fish production (kg /m^3)	No. of lettuce heads (head/m^2)	Lettuce production (kg/m^2)
100	8.20 ^{a}	28	6,21 ^{a}
120	9.84 ^{a}	28	7.22 ^{b}
140	12.14 ^{a}	28	8.65 ^{c}

^{abc} Values in the same column with superscripts are significantly different ($P < 0.05$).

The quality of the products while varying the stocking density was also studied. Nutritional-wise more crude fats and less moisture were achieved by increasing stocking density, while no changes were observed in the crude protein and ash content, as shown in Table 9.

Table 9: Whole body composition of *O. niloticus*

S.D.	Moisture	Ash	Crude Protein	Crude Fat
100	73.7 ^{a}	13.2 ^{a}	55.3 ^{a}	31.8 ^{a}
120	72.8 ^{a}	13.7 ^{a}	55.4	31.4 ^{a}
140	73.5 ^{a}	13.5 ^{a}	56.3	30.2 ^{a}

^{a} Values in the same column with superscripts are significantly different ($P < 0.05$)
Body composition expressed as a percentage of dry fish weight

Lettuce *L. sativa* head composition was not affected by the stocking density, as shown in Table 10.

Table 10: *L. sativa* head approximate composition

S.D.	Moisture (WB)	Crude Protein (DM)	Crude Fat (DM)	CHO	Crude Fibre (DM)	Ash (DM)	Energy (KJ/g)
100	95.7 ^{a}	26.0 ^{a}	3.9 ^{a}	3419.0 ^{a}	13.8 ^{a}	22.1 ^{a}	13.4 ^{a}
120	95.9 ^{a}	25.8 ^{a}	3.5 ^{a}	35.2 ^{a}	13.0 ^{a}	22.4 ^{a}	13.9 ^{a}
140	96.4 ^{a}	23.7 ^{a}	3.6 ^{a}	36.8 ^{a}	13.2 ^{a}	22.8 ^{a}	13.5 ^{a}

^{a} Values in the same column with superscripts are significantly different ($P < 0.05$)
Body composition expressed as a percentage of dry fish weight

Table 11 illustrates the quality of water was also affected by the stocking density. It was observed that among other elements Sodium (Na), Copper (Cu) and Zinc (Zn) were not significantly changed while the other elements increased with increasing stocking density. Table 12 shows the performed water quality tests and the effect of feeding frequency on it, water quality parameters changed significantly as stocking density increased.

Table 11: Average of initial/final water mineral content of each treatment in ppm

S.D.	**Ca**	**Na**	**K**	**Mg**	**P**	**S**	**Co**	**Cu**	**Fe**	**Mn**	**Mo**	**Zn**
0	35.6 ^{a}	0.003^{a}	0.01	0.67	1.6	3.6 ^{a}	0.01	0.02	44.3	1.0	3.3	0.01
100	67.8 ^{a}	0.006^{a}	0.02^{a}	0.02^{a}	11.4^{a}	9.1 ^{a}	0.08^{a}	0.02^{a}	62.2^{a}	8.5 ^{a}	7.4 ^{a}	0.04^{a}
120	98.1^{b}	0.003^{a}	0.03^{b}	0.04^{b}	19.8^{b}	20.0^{b}	0.08^{b}	0.02^{a}	78.4^{b}	17.1^{b}	17.4^{b}	0.05^{a}
140	109.9^{c}	0.004^{a}	0.03^{c}	0.03^{c}	45.9^{c}	38.5^{c}	0.09^{c}	0.03^{a}	76.5^{c}	22.0^{c}	51.3^{c}	0.04^{a}

^{abcd} Values in the same column with superscripts are significantly different ($P < 0.05$)

Table 12: Average of water quality parameters of each treatment in two months

S.D.	Dissolved Oxygen (mg/l)	pH	TDS (ppm)	Ammonia (ppm)	Nitrite (ppm)	Nitrate (ppm)
100	6.9^{a}	6.5 ^{a}	395.4 ^{a}	1.0 ^{a}	0.2 ^{a}	5.3 ^{a}
120	6.1 ^{b}	6.1 ^{b}	666.1 ^{b}	1.5 ^{b}	0.6 ^{b}	17.8 ^{b}
140	5.4 ^{c}	6.2^{c}	932.1 ^{c}	1.1 ^{c}	1.2 ^{c}	22.6 ^{c}

^{abc} Values in the same column with superscripts are significantly different ($P < 0.05$)

4.2 Discussion

In Aquaculture, which is the culture of aquatic organisms commonly referred to as animals in a designated water body wherein the water needs to be treated whenever the toxicants in it have built up beyond animal’s safe level. Toxicants such as ammonia and nitrite are derived from the decomposition of unconsumed feed and metabolites or a waste of the animals. Hydroponics is the culture of aquatic plants in soilless water where nutrients for plant’s growth come entirely from a formulated fertiliser. Aquaponics (a portmanteau of the terms aquaculture and hydroponics) integrates aquaculture and hydroponics into a common closed-loop co-culture where a symbiotic relationship is created in which water and nutrients are recirculated and reused, concomitantly fully utilised and conserved.

In an aquaponics system, waste organic matters from aquaculture system, which can become toxic to animals, are converted by microbes into soluble nutrients for the plants and simultaneously, hydroponics system has already treated the water and recirculates back to aquaculture system with cleansed and safe water for the animals. Besides its ecological merits, aquaponics system can obtain extra economic advantages: saving cost (input) on water treatment for aquaculture system, saving another cost on formulated fertilizer for hydroponics system and benefit from double outputs, harvest of animal and plant, by a single input, fish feed (Liang & Chien, 2013).

The aquaponics system has been modified from its original design to different versions that are currently in use, like the aquaponic lettuce (*L. sativa*) and tilapia production system in Hawaii with a goal to lower the capital and operational costs (Baker, 2010). Their study of the technology indicated that the system setup could vary and be modified depending on the farm's location and hardware availability, though optimal conditions can only be achieved under appropriate aeration, feed, and biomass density (i.e. some fish in the tank). Aquaponic food production is highly efficient because it re-uses the nutrients contained in fish feed and fish faeces to grow the crop plants in an ecological cycle (Love *et al.*, 2015).

Its potential to improve sustainability is discussed regarding food security and as an alternative to intensive fisheries or aquaculture, by efficiently managing the food-water-energy-nexus (Kloas *et al.* 2015). Essential technical components of aquaponic systems are the fish tanks and plant grow beds, while dedicated biofilters and settlers are optional and depend on the configuration of the system. The microbial community was central, not only to the catabolise of the organic matter contained in the faeces and feed residues but also for the conversion of the fish-generated ammonia to nitrate (Kloas *et al.* 2015; Bittsanszky *et al*., 2015).

The current research was conducted as a two-way experiment; one with the increase in feed frequency like once a day, twice a day and thrice a day. The second experiment was conducted by alternating the fish ratio in the fish stocking tank like 100 fish/m^3, 120 fish/m^3 and 140 fish/m^3. Each experiment was conducted in triplicate, and the experimental period for each was three months. The results of the experiments are discussed as follows.

4.2.1. Feeding Frequency

In the present study, Tilapia *O. niloticus* growth, feed utilisation and feed conversion values as related to feeding frequencies, initial weights and mortality rate was similar in all treatments. However, the final weight, weight gain, feed intake and feed conversion ratio significantly increased in those experimental tanks where fish were fed three times a day, followed by those tanks with fish fed twice and once a day. When the feeding frequency was increased, the feed intake, feed conversion ratio, i.e. FCR were increased and the fish production also improved. Similarly, the present findings are in agreement with, Liang & Chien (2013) report that higher feeding frequency is well-effected tilapia survival, weight gain, feed intake and FCR increment. Liang & Chien (2013) also concluded that higher feeding frequency with less feed quantity at a time can result in higher absorption efficiency and lower excretion into the water, consequently, less nutrient accumulation in water.

In an intensive culture of fingerling walleye *S. vitreum*, Phillips *et al.*(1998) found that higher frequency feeding resulted in higher daily DO and lower TAN but did not affect fish growth and size distribution. The present statement agrees with the suggestions of (Riche *et al.*, 2004) who found that feeding tilapia at intervals shorter than the time required for their turn of appetite can lead to gastric overload resulting in reduced absorption efficiency. Their turn of appetite following a satiation meal is defined as the point at which consumption is equivalent to the amount of the previous meal evacuated, and this is approximately 4h in Nile tilapia held at 28°C which we used in our study.

In the present study Tilapia *O. niloticus* body proximate composition analyses showed that crude protein level showed slight increase in fish fed once/day feeding frequency as compared to the others (two and three times per day). Tilapia body fat was increasing with increasing feeding frequencies while body moisture was lowered with increasing frequencies. Tilapia body ash level showed similar in all system. These results showed that the higher feeding frequencies produced fish with more crude fat and less moisture level. This indicates that fish fed lower feeding frequencies were more efficient in utilising experimental feed than those fed higher frequencies improving FCR percentage of the gain. On the other hand, increasing the frequency of feeding in tilapia produced larger fish. The present findings are in agreement with similar observations which were reported by some researchers (e.g., Tung & Shiau, 1990; NRC, 1993; Pouomogne & Ombredane, 2001). Also, the present findings are highly by the findings of previous researchers (e.g., Zhou *et al.*, 2003; Kurtikaya & Bilgüven, 2015; Lanna *et al.*, 2016) who had reported that the higher feeding frequency is useful in tilapia fish species.

The higher feeding frequency, Resulted in the higher body fat and the less body moisture and protein. The present results are highly in agreement with the findings of Yousif (2004). In his study, he had emphasised the effects of feeding frequency on growth performance and feed utilisation efficiency of Nile tilapia juveniles. Significantly higher ($P<0.05$) live weight gain, and protein efficiency ratio (PER) and lower Feed conversion ratio, proximate body composition was achieved by receiving either 3 or 4 meals a day. At the same time, the present findings disagree with (Riche *et al.*, 2004) evaluated statement in the consumption, growth, and feed utilisation of juvenile Nile Tilapias which were fed with a commercial diet once, twice, thrice or five times a day. No significant differences in growth, feed efficiency, or protein utilisation among the fish fed 2, 3, or 5 times daily, but all were significantly better than fish which were fed once. This could be explained by feeding small amount as a percentage of the fish body weight as compared to feeding to satiation in our study.

Also, in this current study, we observed the better production of lettuce *L. sativa* in three times feeding frequency/day experimental aquaponics system with a better yield of Tilapia production. The results indicate that the three-time/day feeding frequency is more suitable for recirculation aquaponics of tilapia, lettuce *L. sativa* culture. In the present investigation, the produced Lettuce *L. sativa* head proximate composition like moisture, crude protein, crude fat, crude fibre, carbohydrates and total energy were shown to be none significantly different between treatments. These results revealed that the feeding frequencies did not affect the lettuce *L. sativa* head proximate composition, but the feed frequency affected the yield of lettuce *L. sativa* for marketing purpose. The present findings are in agreement with the findings of

Liang and Chien, (2013) and Rakocy, *et al*. (1997) who stated that higher feeding frequency would have an effect on plant growth, weight gain and yield performance.

In this experiment, the nutrients content (micro and macro minerals) of the aquaponics water samples were analysed once every fifteen days. The monthly average mineral content like Sodium, Copper and Zinc were not significantly affected, but other elements showed an increase with higher feeding frequency, like. Ca, K, Mg, P, S, Co, Fe, Mn, Mo whose levels had increased in higher feeding frequency which was expected. So, the present results revealed that the higher feed frequency increases the nutrient level in water which in turn yields a better production of quality lettuce *Lactuca sativa*. Also, water quality maintenance plays an essential role in an aquaponics system. The present results are similarly in agreement with relevant work (e.g., Fitzsimmons, 1991; Marschner, 1995; Seawright, 1998; Rakocy *et al.*, 2006; Liang & Chien, 2013). The thesis's findings and suggestions were that macronutrients and micronutrients which are released from fish feed and excretion are essential for proper plant growth. The nutrients are affected by the amount of feed put into the system, the fish to plant ratios, and environmental parameters.

It was indicated that water dissolved oxygen and pH plays a vital role in aquaponics system tilapia culture and Lettuce *L. sativa* cultivation (Rakocy *et al*., 2006). In this study, the higher feed frequency experiment showed the slightly low level of Dissolved Oxygen (DO) and pH level; but it was within the acceptable level of tilapia growth. Also, total dissolved solids, electrical conductivity, Ammonia, Nitrite and Nitrate levels had significantly increased in higher feeding frequency. That was due to a higher amount of feeding with increase feeding frequency. The fish excretes ammonia which converted to nitrate for plant growth purpose. The nitrification process shows an increase in those experimental systems with increased feeding frequency. The present findings are similarly in agreement to (Goto *et al*., 1996; Phillips *et al.*, 1998; Rakocy *et al.*, 2006; Graber & Junge, 2009) findings. They suggested that the feeding frequency is an essential factor in aquaponics.

It is essential to maintain high DO levels in aquaponics systems to have healthy roots & also to eliminate or reduce toxicants in water. The higher frequency feeding resulted in higher daily TAN and lowered DO but did not affect fish growth and size distribution that was because the change were with accepted level. Our present results were not in agreement with the statement from (Liang & Chien, 2013). He found that higher feeding frequency produced lower ammonia and nitrate levels in water, but the dissolved oxygen statement was similar. Any other studies similar to ours can not support his resulted.

4.2.2 Stocking Density

The stocking density of fish is considered as one of the critical factors in aquaponics, besides feeding rate and frequency since it varies according to fish type and species. In aquaponics systems, especially for intercropping, stocking density must be ideal and optimum to ensure that the waste is converted to ammonia and nitrate in the final phase. Through the optimal stocking density, one can obtain maximum production without effects on the environment, optimum health, economic benefits (Rahman & Marimuthu, 2010) and minimum occurrence of physiological and behavioural disorders (Ashley, 2007; Ayyat *et al*., 2011).

In the present aquaponics experimental study, the second experiment was to measure the optimum stocking density of tilapia. That tested densities were 100 fish/m^3, 120 fish/m^3 and 140 fish/m^3 levels. In the present study, the initial weight and mortality rate were similar in all treatments (100 fish/m^3, 120 fish/m^3 and 140 fish/m^3). The final fish production, weight gain and feed intake showed better result in 100 fish/m^3 when comparing with other treatments (120 fish/m^3 and 140 fish/m^3. In the production of tilapia, there was a significant increase in higher stocking densities (140 fish/m^3) experiment as compared to all other treatments. Also, lettuce *L. sativa* production in per square meter was significantly higher in a high density of the fish experimental system. That was probably due to a higher amount of feed with higher stocking densities.

Tilapia *O. niloticus* approximate body composition showed that lower stocking densities produced fish with more crude fat and less moisture while crude protein and ash were not significantly different in comparison to the higher stocking density. The results indicate that tilapia and lettuce *L. sativa* production increased significantly in the highest stocking densities of fish. The present findings are similarly in agreement with relevant work (e.g., Rahman, 2005; Gibton *et al.*, 2008; Ridha, 2005; Rashid, 2008; Alam, 2009; Rahman & Marimuthu, 2010; El-Salam *et al*., 2014). They suggested that the increase of fish stocking density produced a high yield in the same amount of feed when compared with lower densities of fish.

The higher density produced better yield whereas lower density produced only larger fish size with feed lower conversion ratio. The present results are disagreed by (Ahmed & Hamad, 2013) in their statement which is, increasing the stocking density from 100 to 200 fish/m^3 in the fish tank results in adverse impact by reduced survival, growth and benefits. That was probably due to their experimental condition which affected the carrying capacity of the unit of water which was not the case of our study. On the other hand, another study conducted by (El-Saidy & Hussein, 2015) on the effect of low stocking density (50 fish/m^3) inferred that there is a positive effect on growth performance and feed utilisation parameters. However, farmers and commercial producers always look for the optimum stocking density to achieve maximum profits.

Also, in this study, the better approximate composition in cultivated lettuce *L. sativa* head shows moisture, crude protein, crude fat, crude fibre, carbohydrates and total energy are similar in all treatments. However, the total production of Lettuce Lactuca sativa showed a better yield in the experiment with a higher density of fish. In other words, fish stocking densities did not have a significant effect on lettuce *L. sativa* head biochemical composition, but it affected the plant growth and weight gain. The present results are in agreement with (Licamele *et al*., 2009; Fytianos & Zarogiannis, 1999; Muramoto, 1999). They suggested in their findings that, plants use ammonia and nitrates for growth.

Nitrate is taken up by the plant at better rates than ammonia and nitrite which can be toxic to plants. Ammonia concentrations at elevated levels can inhibit nutrient uptake in plants by altering the ionic capacity of the water medium. The central part of the existing nitrogen is absorbed by the plant roots and serves as a starting material for synthesis of proteins and other nitrogen compounds. Nitrates and nitrites are present both as undesirable contaminants. Our results showed water in all treatments had much lower levels of ammonia, nitrites and nitrates than any level which could have adverse effect on fish .

The change of water quality in the experimental aquaponics systems initial and final mineral content of water were analysed. The initial mineral content of water was similar and significantly lower than that of each treatment after the three months' experimental duration as expected. Sodium, copper and zinc were not significantly affected while other elements had significantly increased with higher stocking densities. The present results indicate that the higher density of fish did not affect water content of sodium, copper and zinc which indicate fish gills and plant roots absorb all these elements that were released from fish waste .

The other elements were increased with increasing stocking densities. This could be explained by increasing the amount of feed and consequently, increasing the other elements above lettuce roots could absorb. Lettuce cultivation yield shows better results in high-density stocking aquaponics system. In other words, lettuce production was higher with higher stocking densities, and roots absorption requires certain concentration to increase their absorption Prior studies have shown that lettuce *L. sativa* in an aquaponics system can be produced with similar growth as hydroponics solution (Licamele *et al.*, 2009).

In the present investigation, the high density of fish stocking experiment showed the slightly low level of Dissolved Oxygen and pH level; but it is the optimal level. Also, the total dissolved solids, electrical conductivity, Ammonia, Nitrite and Nitrate level had increased significantly in high-density stocking aquaponics system. The fish excretion with high ammonia is converted to nitrate for plant growth purpose. An increase in the level of nitrate was noted in a high density of fish stocking aquaponics system. The results indicate that the nitrification process is high in this system, which helps to increase the yield of Lettuce *L. sativa* production. The present findings are in agreement with (Rahmatullah *et al*., 2010) statements. He stated that the high densities of fish do not affect the water quality parameters. Water quality is maintained at acceptable level but DO level had decreased due to the high metabolism of fish,

In conclusion, this study revealed that high feed frequency (3 times/day) and high density of fish stocking (140 fish/m^3) produced a significantly higher production of tilapia and lettuce head yield without any effect on the water quality. Also, the high feeding frequency and high density of fish ratio are very effective and suitable for greenhouse recirculation aquaponics systems in UAE condition. It has produced a better yield of fish and lettuce *L. sativa* without affecting the environmental system. The present results revealed that the high feeding frequency and high density of fish stocking are useful for sustainable and prosperous aquaponics (Fish and leafy vegetable cultivation) business for UAE farmers.

Chapter 5: Enterprise Budget Analysis

5.1 An Overview

This chapter is devoted to the discussion on the economic analysis of this enterprise budget of the aquaponics system considered in this research. This study considered the impact of varying fish feeding frequency and stocking density on the quality of the organic lettuce produced, and so produced different enterprise budget outcomes. The system of Aquaponics is employed in this study. Two rounds of experiments accomplish this; the first experiment studied the effect of different feeding frequency on the operation and total costs when inputs used changed. As a consequence, the study considered the impact of feeding frequency on revenue while inputs change and the result of net returns. Meanwhile, in the second experiment similar enterprise analysis was completed for varying stocking density instead of feeding frequency. The methods used are discussed in the following two sections below.

5.2 Method of Calculating the Enterprise Budget

To develop an enterprise budget, the scope of the system was defined, which is the effect of feeding and stocking Tilapia *O. niloticus* on the quality of producing lettuce. Income and expenses are defined for the system. To develop that enterprise budget, the following assumptions were considered:

i) The system is devoted to the Aquaponics production of tilapia and lettuce.

ii) The financial analysis included the calculation of revenues (quantities of output by multiplied prices for both fish and vegetable), the variables costs (i.e. operational expense), the fixed cost (annual allocation of depreciation of all assets used in the experiments). Net returns were then calculated after subtraction of both the variables and the fixed cost for both fish and vegetable, and the cash flow for the allocated scenarios.

iii) The enterprise budget was considered as annual revenues, costs and returns (the duration of the experimental values of the three months. However, enterprise budget figures/values were scaled to one year).

iv) The economic parameters varied as the feeding frequency, three scenarios based on different feeding per day were investigated (1-time, 2-times and 3-times).

v) The economic parameters varied as the stocking density, three scenarios of a different number of fish per cubic meter were investigated (100, 120 and 140 fishes).

vi) The enterprise budget assumed prices of inputs and outputs are fixed to study only the impact of changing feeding frequency and stocking of fish variability.

vii) The enterprise assumed the market prices of the inputs and output without considering real cost when government subsidies of resources such as water and electricity are considered. A further study may consider the net cost after the government subsidies are subtracted.

The income is the value received from the sale of the system products to a corresponding enterprise of fish and vegetable sales. The expenses included two categories which are the fixed cost (fixed assets) and the variable cost (operating costs). For this system, the fixed cost includes the expenses of the greenhouse structure, excavation, lining, stabilisation, plumbing, electric hook-ups, storage sheds, aerators, floating piers, cages, scales, water analysis gear and miscellaneous.

The fixed cost does not change with other business activities like increase or decrease in output and sales. On the other hand, variable cost includes the expenses of purchasing fingerling, seeds of vegetables, chemicals used, feed consumption, labour, electricity, water, marketing, packaging and miscellaneous. The total cost is the summation of the fixed and variable costs. The revenue is whatever gained from the business activities of the system. The gross margin signifies the retains after covering the variable cost of each dollar of sales, it is found from the following equation:

$$\text{Gross Margin (AED)} = \text{Total Revenue (AED)} - \text{Variable Cost (AED)} \tag{3}$$

The total earnings of a company are represented by the net income which is:

$$\text{Net Income (AED)} = \text{Total Revenue (AED)} - [\text{Fixed Cost (AED)} + \text{Variable Cost (AED)}] \tag{4}$$

$$\text{Net income contribution to cover the total cost (\%)} = \frac{\text{Net Income (AED)}}{\text{Total Cost (AED)}} * 100 \tag{5}$$

Budget analysis is developed for the two experiments of this study taking into account the impact of feeding frequency and stocking density. Results of these equations (FAO, 2018) are discussed in the following sections 5.2 and 5.3 that include the discussion and impact of feeding frequency and stocking density.

5.3 Impact of Feeding Frequency on the Enterprise Budget

Enterprise budget was developed for the feeding effect of Tilapia *O. niloticus* on the quality of the produced lettuce. This is done by defining the costs and revenues to determine the gross margin and net income over fixed and variable costs as well as the net income percentage over fixed cost. Over a three-month period of study three scenarios with different feeding, frequencies were scaled to one year and investigated.

5.3.1 Feeding Frequency Impact on Enterprise Economic Elements

Table 1 shows that the variable cost (operating cost) estimated is slightly increased with increasing the feeding frequency of Approximately extra AED 100 as feeding frequency times per day from 1-time to 2-times and from 2-times to 3-times per day. The reason of that is obviously that the inputs increased operational (variable) costs with increasing feeding times per day; (i.e. for the first scenario of 1-time per day feeding the input of money was once doubled for the second scenario and tripled for the third scenario). The maximum variable cost was observed in the third scenario AED 55,693.

Table 13: Enterprise budget change due to feeding frequency variability in AED

Feeding Frequency (Time/day) in AED	**1.0**	**AED/Kg**	**2.0**	**AED/Kg**	**3.0**	**AED/Kg**
Fish Price per Kg	-	10	-	10	-	10
Vegetable price per Kg	-	3.5	-	3.5	-	3.5
Fixed Cost	33,349	2.77	33,349	2.77	33,349	2.77
Variable Cost	55,497	3.93	55,605	3.94	55,693	3.94
Total Cost	88,846	7.39	88,954	7.40	89,042	7.40
Total Revenue	122,527	-	122,410	-	123,43	-
Gross Margin	67,030	-	66,805	-	67,743	-
Net Income	33,681	-	33,456	-	34,394	-
Contribution of net income to cover total cost (%)	37.9	-	37.6	-	38.6	-

A similar trend was observed for the total cost that similarly increased by Approximately extra AED 100 with increasing the feeding times per day from the first to the second scenario and from the second to the third scenario. Proportionality increases with feeding frequency for AED 88,846 to AED 88,954, to AED 89,042. This is simply because the total cost is the addition of the fixed and variable costs, which are both displayed in table 5.1. The fixed cost of the three scenarios was found to be similar which AED 33,349 is because it is independent of other business activities. Moreover, all of the other variables/ parameters should be fixed to obtain reliable results from the experiments.

The second economic element of this enterprise budget is the total revenue. Total revenue perceived an increase with increasing the feeding frequency which resulted in an increase in production that gives more income. Total revenue changes were found to be more evident in the feeding frequencies experiments. The maximum total revenue was observed in the third scenario AED 123,436. However, for the second scenario where the Tilapia was fed twice a day the net revenue decreased. The varying experimental output justifies this regarding fish and lettuce production. The gross margin is the subtraction of the variable cost from the total revenue. So, it is strongly dependent on the experimental output that contradicted the expected trend for the second scenario.

The third part of the enterprise budget analysis considered the net income which is the subtraction of the total cost, i.e. the variable cost and the fixed cost of the total revenue. The revenue that strongly depends on the experimental output (production), in the last paragraph it was mentioned how the revenue changes are higher values the second scenario compared to the first scenario. Likewise, the income is increasing with increasing the feeding frequency; the second scenario is higher because of the unexpected output for that specific experiment. The last raw in the table shows the contribution of the income to cover the total cost, which means that the system is profitable, and can return an acceptable return on its investment.

5.4 Impact of Stocking Density on the Enterprise Budget

Enterprise budget was developed once again for stocking effect of Tilapia O. Niloticus on the quality of lettuce. This time it is done in a similar manner that is shown in section 5.2, over the similar three-month period of study another three scenarios with different stocking densities was investigated which are: 100 fish/m^3, 120 fish/m^3 and 140 fish/m^3, results are displayed in Table 2.

5.4.1 Stocking Density Impact on Enterprise economic Elements

In table 5.2, the variable cost (operating cost) perceived a considerable increase with increasing the stocking density only by 20 fishes per grazing area. The variable cost increased by Approximately extra AED 5,000 with increasing stocking density from; 100 fish/m^3 to 120 fish/m^3 and from 120 fish/m^3 to 140 fish/m^3. The reason of that is apparently that the input of fish increased with increasing the density, i.e. within the three scenarios the operation of the system required more expenses while increasing the input of fish to the system and thus the stocking density.

Table 14: Enterprise budget change due to stocking density variability in AED

Stocking Density (fish/m^3) in AED	**100**	**AED/Kg**	**120**	**AED/Kg**	**140**	**AED/Kg**
Fish Price/Kg	-	10	-	10	-	10
Vegetable price/ Kg	-	3.5	-	3.5	-	3.5
Fixed Cost	33,349	2.77	33,349	2.31	33,349	1.98
Variable Cost	81,829	3.94	86,805	3.63	91,797	3.40
Total Cost	115,178	9.61	120,154	8.30	125,146	7.42
Total Revenue	122,714	-	147,166	-	171,783	-
Gross Margin	40,885	-	60,361	-	79,986	-
Net Income	7,536	-	27,012	-	46,637	-
Contribution of the net income to cover total cost (%)	6.5	-	22.5	-	37.3	-

The similar trend was observed for the total cost that similarly increased with increasing the stocking density per grazing area from the first to the second scenario and from the second to the third scenario. Proportionality increases with feeding frequency for AED 115,178 to AED 120,154, to AED 125,146. Moreover, again, this is because the total cost is the addition of the fixed and variable costs, which are both displayed in table 5.2. Also, because the fixed cost of the three scenarios is independent of other business activities AED 33,349. Furthermore, all of the other parameters are fixed to obtain reliable results from the experiment.

This enterprise budget also considered the economic element of this enterprise is the total revenue. Total revenue has perceived a considerably high increase with increasing the stocking density which resulted in an increase in production that gave more income. This increase in the revenue was by Approximately AED 25,000 by increasing only 20 fishes in the stocking area; this means potential high profitability by increasing the stocking density more than increasing the feeding frequency that increased the revenue by only a few hundred. Meanwhile, the maximum total revenue was observed in the third scenario to be AED 171,783.

The gross margin is the subtraction of the variable cost from the total revenue, and it was increasing by AED 20,000 with increasing the stocking density each time. Another element is the net income which is the subtraction of the total cost from the total revenue, i.e. the variable cost and the total cost. Also, because it is dependent on the revenue that depends on the experimental output, a high increase in the income was observed with increasing the stocking density. The last row in the table shows the contribution of the income to cover the fixed cost; this exceeded 70% at the maximum stocking density, which means that the system is profitable, and can give an acceptable percentage of its initial investment.

5.5 Summary of the Enterprise Budget Analysis

In conclusion, it was noticed that the impact of stocking density is more significant than the impact of feeding frequency on the economic enterprise budget, yielding higher returns and incomes of the investment. Furthermore, the quality of the produced tilapia fish and lettuce was also confirmed by different test taking into account various parameter. As feeding frequency increases from 1, 2 to 3 a day, the net income over total cost was found to be 37.9%, 37.6% and 38.6% respectively. As stocking density increases from 100 fish/m^3, 120 fish/m^3, to 140 fish/m^3 respectively. The net income over total cost was found to be 6.5%, 22.5% and 37.3%. Example of the enterprise budget is shown in Appendix B.

Chapter 6: Conclusion and Future Work

The proposed aquaponic system offers a promising enhancement to the production of tilapia and lettuce in the UAE. This is expected to encourage the investors in the field to perform business in the country and the region, as well, knowing that the Arabian Peninsula has a similar climate conditions and common obstacles of water scarcity, lack of rainfall, high summer temperatures, high evaporation rates and increased electricity consumption due to the rapid population growth.

The quality of the production of tilapia and lettuce using the aquaponic system was studied in this system. Although the limited use of the system in the region this study showed potential productivity and profitability. The effect of different daily fish feeding frequency was studied for three different scenarios of 1-time per day, 2-times per day and 3-times per day. Also, the effect of varying fish stocking density was studied as well, with three different scenarios of 100 fish/m^3, 120 fish/m^3 and 140 fish/m^3.

The quality of the products from the system was investigated using different test methods. To confirm the optimum feed conditions, feed utilisation and conversion possibility were tested. Moreover, to confirm fish quality weight gain, feed intake and fish mortality were tested as well. Furthermore, to confirm the quality of the produced lettuce the nutritional components ratios were investigated, namely moisture, crude protein, crude fat, crude fibre, carbohydrates and total energy. Lastly, the quality of water and growth conditions of the system was evaluated by tracking different water quality parameters namely: pH, total dissolved solids (TDS), dissolved oxygen (DO) and ammonia and nitrate content in the water. It was concluded that the maximum feeding frequency of three times per day and the maximum stocking density of 140 fish/m3 are recommended to achieve maximum profitability. It is also recommended to use either of them with any selection of the other one, based on the business requirements of the system.

Enterprise budget analysis was employed to predict the profitability of the proposed scenarios to that was evaluated in the aquaponic system. It was found that increasing the stocking density can offer a better improvement in the profitability of the system rather than increasing the feeding frequency. The highest obtained net incomes were AED 34,394 contributing with 38.6% to cover the cost and AED 46,637 contributing with 37.3% to cover the cost for varying feeding frequency and varying stocking density respectively. Even at low feeding frequency and stocking density the system showed potential profitability of the investment.

More comparative studies for other production systems for lettuce and fish are needed in the future to address the fact that there is little information about the optimum conditions of the system to date. Also, it is important to encourage local business and investors to increase utilisation of this system, and involvement with universities and researchers to maximise production, returns and incomes based on scientific efforts. Also, for future research, it seems decent to study other factors in the aquaponic systems, like using different water resources, feed products and locations of the system. Also, it is essential to study the system at different temperatures, humidity rates and altitudes. Based on literature survey, other fishes and vegetables can be tested using the current system like ornamental fish, barramundi fish, tomatoes, bell peppers, cucumbers, peas and squash.

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Appendix: Enterprise Budget Analysis Sample

A sample excel spreadsheet where the calculation of the enterprise budget was done, is displayed in the following chart, it is from the first experiment for the first scenario "1-time of feeding per day".

Sample enterprise budget analysis

Aquaponic System Enterprise Budget in Dirham's					
Tank size:	$15\ m^3$ GH1				
Production time frame:	1 year				
INCOME					
Number of fish stocked					6,200
Survival rate					0.97
Total fish produced					6,014
Average sale weight (Kg)					**2**
Total sale weight (Kg)					12,028
Price per Kg					10.00
Veg. Kg					642.00
Vegetables Sales					2,247
Total Income					**122,527**
VARIABLE COSTS	**Unit**	**Amount**	**Price**	**Total Cost**	**Cost / Kg**
Fingerlings	each	6,200	2.89	17,918	1.49
Total weight gained	Kg	118			
Feed conversion ratio	ratio	1.81			
Seeds for vegetables	Kg			3,000	0.50
Chemicals and IPM				5,250	2,625.00
Total feed consumption	Kg	433	0.15	65	0.01
Labour for Fish Operation	hour	2		12,000	1.00
Electricity and Water	year			6,000	0.50
Marketing & packaging	fish	24,056	0.25	6,014	0.50
Miscellaneous	year	4	500	3,000	0.25
Interest on variable costs		44,997.02	0.05	2,249.85	0.19
Total variable costs				55,496.87	3.93
Net income over variable costs				**67,030.13**	**6.07**

Sample enterprise budget analysis

FIXED COSTS	**Costs**	**Salvage Value**	**Years Used**	**Cost / Year**	**Cost / Kg.**
Greenhouse Capital Cost	325,000	0	15	21,667	1.80
Excavation	9,000	0	15	600	0.05
Lining	6,000	0	15	400	0.03
Stabilization	3,676	0	15	245	0.02
Plumbing	5,100	0	15	340	0.03
Electric hook-up	4,980	0	15	332	0.03
Storage shed	5,320	0	15	355	0.03
Aerator	2,561	0	5	512	0.04
Floating pier	7,316	0	5	1,463	0.12
Raceway	5,487	0	5	1,097	0.09
Scale	915	0	5	183	0.02
Water analysis gear	0	0	5	0	0.00
Miscellaneous	3,731	0	5	746	0.06
Total Fixed Cost	379,086				
Interest and added value tax on fixed costs	5,409			5,409	0.45
Total fixed costs				33,349	2.77
Total variable and fixed costs				**88,846**	7.39
Net income over variable & fixed costs				**33,681**	**2.80**