



**EFFECT OF AQUAPONIC SYSTEMS ON WATER QUALITY, GROWTH
PERFORMANCE OF NILE TILAPIA AND GROWTH AND YIELD OF VEGETABLES**

M.Sc. THESIS

BY

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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**A THESIS SUBMITTED TO THE
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OCTOBER, 2023

DECLARATION

I declare that the thesis entitled “**Effect of aquaponic systems on water quality, growth performance of Nile tilapia and growth and yield of vegetables**” is my own work. All the sources that I have used or quoted have been indicated and acknowledged by means of complete references. I solemnly declare that, this thesis is not submitted to any other institution or anywhere for the award of any other academic degree, diploma or certificate.

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(Submission Sheet-1)

This is to certify that the thesis entitled “EFFECT OF AQUAPONIC SYSETMS ON WATER QUALITY, GROWTH PERFORMANCE OF NILE TILAPIA AND GROWTH AND YIELD OF VEGETABLES” Submitted in partial fulfillment of the requirements for the degree of **Master's** with specialization in **Aquaculture and Fisheries Management**, the Graduate Program of the **Department of Aquatic Sciences Fisheries and Aquaculture (ASFA)**, and has been carried out by JALANE DIDA AKESA, ID. No GpFiAqR/0003/14 under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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LIST OF ACRONYMS AND ABBREVIATIONS

BFOALRC.....	Batu Fish and Other Aquatic Life Research Center
CF.....	Condition Factor
EIAR.....	Ethiopian Institute of Agricultural Research
FCR.....	Food Conversion Ratio
FMTL.....	Fish Mean Total Length
FMBW.....	Fish Mean Body Weight
MB.....	Media Bed
MBWG.....	Mean Body Weight Gain
MSY.....	Maximum Sustainable Yield
NFALRC.....	National Fisheries and other Aquatic Life Research Center
NFT.....	Nutrient Film Technique
RAS.....	Recirculating Aquaculture System
SR.....	Survival Rate

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Abstract

*Aquaculture production is one of an alternative food producing sector. Compared to different alternative ways of aquaculture production, aquaponics system is preferable to mitigate food and nutritional security in Ethiopia. Plants and fish have different growth performances in different culture systems. So the present study was designed to assess how the two aquaponic systems (Media Bed and Nutrient Film Technique) affect the water quality and growth performance of Nile tilapia (*Oreochromis niloticus*) and their effect on the growth and yield of tomato (*Solanum lycopersicum*) and lettuce (*Lactuca sativa*). The study was performed from March to May 2023 (12weeks). Four hundred fingerlings of Nile tilapia (*Oreochromis niloticus*) of uniform size were obtained from Batu Fish and Other Aquatic Life Research Center and stocked into fish tanks of the experimental units. However, the tomato (*Solanum lycopersicum*) and lettuce (*Lactuca sativa*) seeds were purchased from Batu local market, germinated on seedbed and transplanted to the experimental units. The experimental fish were supplied 30% protein content commercial feed twice per day. The water quality parameters such as dissolved oxygen, hydrogen ion concentration (pH), temperature, conductivity and salinity were measured once per two weeks and three times per sampling date. The present study revealed that, pH ranged between 9.26 and 9.45, temperature ranged between 24.63 and 25.7°C, TDS ranged between 1.75 and 1.77 g/L, conductivity ranged between 2.3 and 2.4 mS and salinity ranged between 1.21 and 1.3ppt. WG, FCR, CF, SR, FMTL, and FMBW for the media-filled bed system were 40.36 ± 0.19 g, 1.2 ± 0.0 , 2.07 ± 0.05 , $98.59 \pm 0.4\%$, 14.75 ± 0.3 cm, and 60.36 ± 0.19 g, respectively, and for the NFT system, the values were 40.67 ± 0.3 g, 1.2 ± 0.0 , 2.18 ± 0.3 , $98.68 \pm 0.95\%$, 14.1 ± 0.27 cm, and 60.67 ± 0.3 g, respectively. The water quality parameters and growth performance of the experimental fish between the two systems didn't show significant differences at 95% confidence interval ($P > 0.05$). However, the growth and yield of tomato and lettuce in MB was significantly different from that of NFT at 95% confidence interval ($p < 0.05$). Therefore, it was concluded that, the types of the aquaponics systems did not affect water quality, and survival, condition factor, and the growth performance of Nile tilapia, but they did affect tomato and lettuce growth and yield. For good water quality and fish growth, both MB and NFT are recommended, while for better plant growth, MB is recommended.*

Key words: *Aquaponics, Lettuce, Nile tilapia, Tomato, Water quality*

1. INTRODUCTION

1.1. Background of the study

Food security issues are increasingly getting importance as human population is expanding all over the world particularly in developing nations. Over the years, due to increased number of craft and gear and man power, capture fisheries potential available in coastal waters were over exploited and thus capture fisheries has reached the maximum sustainable yield (MSY) (Zhang *et al.*, 2016) and this again forced the development of aquaculture in different water bodies. Due to new directions such as species and system diversification, aquaculture production has surpassed capture fisheries in certain counters (Boyd *et al.*, 2022). Since aquaculture is cultivation of aquatic organisms under controlled environmental conditions, it started showing some constraints which at times leads to heavy mortalities causing severe economic loss to fishing and farming sectors (Shimaa *et al.*, 2020).

Realizing this fact and understanding the importance of aquaculture as one of the major food sources for people of most developing nations, there are intense efforts in bringing more areas under the grove of aquaculture, developing new and improved techniques to increase aquaculture production (Gavin and Allan, 2009). Further, as the growth of urbanization decreased the amount of land available for farming, there is an imperative need for new concepts and technological advancements that might help establish a suitable agricultural production system for developing nations (Gavin and Allan, 2009).

Among various system diversifications, one of the systems developed to increase aquaculture production is integration of fish and plants. This integration helps to achieve better product

output at lower operational cost. Among the various integrated aquaculture, aquaponics has received greater attention in recent years (Milena *et al.*, 2022).

Aquaponics is a profitable food production system combines hydroponics with fish farming, or aquaculture (Vaishali, 2019). The hydroponic component of the aquaculture system circulates the nutrient-rich effluents, some of which are assimilated by the vegetation before the water is lowered back to the fish tanks (Vaishali, 2019). The use of nitrogen in chemical fertilizers has exceeded the nitrogen content of the oceans by 20 times in the last two decades, severely eutrophication our aquatic bodies (Vaishali, 2019). Therefore, it is believed that the only way to improve water and fertilizer efficiency and reduce waste is to close the loop between vegetation and animals. Reducing land use could contribute even more to sustainability (Vaishali, 2019).It is in this connection aquaponics assumed exceptional significance.

The popularity of aquaponics has increased since the 1990s. Around the world, there are a lot of small-scale aquaponics initiatives that include numerous substantial semi-commercial enterprises (Subhendu, 2015). Before 1980s, the majority of attempts made to combine hydroponics and aquaculture failed. However, since the 1980s, aquaponics assumed importance and has become a practical means to produce food (Subhendu, 2015).African countries that embraced aquaponics systems include Egypt, South Africa, Nigeria and Kenya. Where ever there is scarcity of water and space, aquaponics is a suitable option (Dalsgaard *et al.*, 2013). Water circulation between the RAS and hydroponics systems can produce a remarkable water reuse efficiency rate of up to 90% in arid environments (Dalsgaard *et al.*, 2013).

Different fish species and different species of vegetables have been successfully grown in the aquaponics system (Pantanella *et al.*, 2010 and Salam *et al.*, 2014).The team of qualified experts

at Addis Ababa University (AAU) has initiated a research program on the viability of aquaponic systems in Ethiopia (Smart Fish, 2013). The EU-funded FAO Smart Fish Project and the AAU entered into a partnership to help the latter with the promotion and technology transfer of small-scale aquaponics, with the aim of promoting sustainable aquaculture development through the wise use of water (Smart Fish, 2013). In Ziway and Shewa Robit, Ethiopia, the aquaponic demonstration units were developed to provide local communities the knowledge of growing plants and fish in aquaponics systems (Smart Fish, 2013).

Due to the fact that aquaponics culture system is relatively a new technology, more studies are required on the efficacy of different types of aquaponics systems on the growth performance of different types of plants and fish. The present study deals with the water quality, growth performance of Nile tilapia and vegetable crops under two aquaponics system namely media bed units and nutrient film techniques.

1.2. Statement of the problem

Aquaponics offers several advantages for Ethiopia's food system. Firstly, it can produce a year-round supply of fresh vegetables and protein-rich fish, reducing seasonal limitations. Secondly, it requires significantly less water compared to traditional farming methods, addressing water scarcity concerns (Abebe Tadesse, 2023). The major objective of any fish production system is to boost and maintain a high level of average fish growth performance, survival, and adequate water quality. High yields, enhanced economic benefits, and the maintenance of optimum environmental conditions are the end results of these requirements in the fish production system. Numerous aquaculture operations cause the water quality to worsen, resulting in poor fish yields and reduced fish growth performance. A system that combines aquaculture production with a recirculating water system has been proposed to address these challenging situations, and

aquaponics fits in this context very well. The aquaponics system is a new technology in Ethiopia with little documentation on its operation, so its outcome in terms of fish growth performance, survival, and good water quality remains speculative. In addition, there are neither developed and designated protocols and specifications nor standard operating procedures for aquaponics practices in Ethiopia. Therefore, studying the effects of different types of aquaponics on water quality, fish growth, plant growth and yield have become a necessity.

1.3 Objectives of the study

1.3.1. General Objective

To compare the performance and sustainability of media bed (MB) and nutrient film technique (NFT) aquaponics in Ethiopia, with the aim of providing useful information for aquaponics practitioners and researchers.

1.3.2. Specific Objectives

- To compare two types of aquaponic system designs, media bed (MB) and nutrient film technique (NFT), in terms of their effects on water quality, growth performance of Nile tilapia, and growth and yield of tomato and lettuce.

1.4 Research questions

1. How do the water quality parameters of MB and NFT aquaponics systems differ from each other and from the recommended ranges for tilapia and vegetable crops?
2. How do the survival rate, condition factor, and growth performance of Nile tilapia vary between MB and NFT aquaponics systems?
3. How do the growth performance and yield of tomato and lettuce vary between MB and NFT aquaponics systems?

1.6 Scope of the study

This study cover the effects of two aquaponic systems, i.e., the media bed and the nutrient film technique, on the quality of the water, survival rate, condition factor and growth performance of Nile tilapia (*Oreochromis niloticus*) and growth performance and yield of tomato (*Solanum lycopersicum*) and lettuce (*Lactuca sativa*). The deep water culture system was not included because of the availability of only MB and NFT in the study area.

1.7. Limitation of the study

Establishing and operating an aquaponic system is expensive, and the university did not budget for one. Therefore, this research was conducted using an existing aquaponic system at Batu Fishery Research, even though the units were old and worn out. Due to a lack of facilities, nitrate and nitrite data were only collected twice during the study period, which was insufficient to compare the media bed and nutrient film technique methods. However, these data are included in the paper as an indicator of the aquaponic environment. Dissolved oxygen data were collected at the beginning of the experiment, but not for the remainder because the measuring instrument malfunctioned.

2. LITERATURE REVIEW

2.1. Aquaculture

Aquaculture is the controlled captive rearing and cultivation of fish and other aquatic animals and plant species (FAO, 2014). Fish, crustaceans, mollusks, aquatic plants, and algae are just a few of the aquatic species that have been successfully cultivated (FAO, 2014). Freshwater and saltwater fish species are grown in controlled culture environments. Currently, the fastest-growing area of animal food production is aquaculture (Rakocy *et al.*, 2006). The most prevalent type of aquaculture, known as fish farming, entails breeding fish for commercial purposes in enclosures, ponds, or tanks, typically for human consumption (Rakocy *et al.*, 2006).

Aquaculture production techniques have been created in many different parts of the world and have been modified to fit the particular climatic and environmental circumstances of those places (FAO, 2014). Open-water systems (such as cages and long lines), pond culture, flow-through raceways, and recirculating aquaculture systems (RAS) are the four main subcategories of aquaculture (FAO, 2014). In a RAS operation, water that has been cleaned and filtered is then used again for the fish. A RAS might significantly boost productivity per unit of land and is the most effective water-saving method in fish farming, even though it is expensive production system because of greater investment, energy, and operation expenses (FAO, 2014). Due to the potential for by-product usage and higher nutrient concentrations in the water for vegetable crop production, a RAS is the most practical technology for the improvement of integrated aquaculture agriculture systems (FAO, 2014).

2.1.1. World Aquaculture

Aquaculture developed as an alternative to capture fisheries and to meet the food demand of the growing human population (Edwards, 2013). Within the last fifty years, the global aquaculture production has expanded and transformed into a significant industrial activity (Edwards, 2013). Farmers are still under pressure to enhance production to meet their livelihood and to solve the food insecurity issues (Edwards, 2013 and Edwards, 2015). The aquaculture sector is projected to produce more fish in order to keep up the demand for the expanding global population (Edwards, 2015).

2.1. 2 Aquaculture in Ethiopia

The construction of pond cultures for various indigenous and non-indigenous fish for experimental purposes marked the beginning of aquaculture activities in Ethiopia in the 1970s (FAO, 2003). The Sebeta Fish Breeding and Research Center launched Ethiopia's fish farming industry in 1975. The Ethiopian Institute of Agricultural Research (EIAR) has designated this facility, which is currently known as the National Fisheries and other Aquatic Life Research Center (NFALRC), to undertake and coordinate fisheries, limnology, and aquaculture research (Rothuis *et al.*, 2012).

The first initiative involves replenishing and improving man-made lakes, reservoirs, and other minor bodies of water in order to stimulate substantial aquaculture (FAO, 2011). Other than fisheries based on culture, aquaculture is less common in Ethiopia. The creation of more regulated aquaculture operations is still in its infancy. However, according to FAO (2011), the aquaculture sub-sector's production has gone from 15 to 25 tons annually.

Following the creation of the "National Aquaculture Development Framework of Ethiopia" by the Ministry of Agriculture and Rural Development, aquaculture practices were established in various regions of the nation (Rush, 2012). As a result of regional and national fish research centers, universities, and other supporting organizations, various cage culture, pond culture, hatchery, fish diet, integrated aquaculture, and aquaponics activities have been launched in several locations. However, aquaculture continues to play a little role in overall fish output (Rush, 2012).

2.2 Hydroponics

Hydroponics is the technique of growing plants using water as medium rather than soil. It involves adding of nutrient solution containing all the nutrients necessary for optimal plant growth (Seerat *et al.* 2020). Due to growing economic pressure to produce high-quality plants under more stable conditions, hydroponic production becomes increasingly intense and complex with time (Rush, 2012).

Different kinds of inorganic fertilizers are used in solution form in hydroponics to promote the growth of plants. It is reported that excess use of fertilizers in fields for growth of agricultural products directly change the climatic conditions of the world (Seerat *et al.*, 2020). Additionally, it is anticipated that the addition of nutrients and unused nutrients will cause environmental contaminants (Licamele, 2009). Aquaponics system would help in reducing the contaminants in the culture system. Despite its potential for improving food and nutrition security, hydroponic technology is still not widely used in developing nations due to limited availability and prohibitive costs (Licamele, 2009).

The nutrients used in hydroponics are derived from the waste products of various animals, such as fish or ducks, or from nutrient solutions created in research labs (Hanan, 1998). Due to the need for year-round availability of vegetables, farmers are spending exorbitant amounts of money to produce vegetables (Hanan, 1998). In hydroponic systems, the roots of the plants are submerged in a hydroponic solution designed to promote healthy plant growth (Hanan, 1998). As plants are grown in an aqueous medium, there is less risk of soil-borne diseases using hydroponic production techniques (Resh, 2001).

2.2.1 Hydroponics in Ethiopia

There are some hydroponic initiatives that have taken place in Ethiopia where strawberries and flowers were produced, but they are in their infant stage (Shumet Afrassie, 2023). For the production of products, the companies using extremely high costs of inorganic salts to prepare hydroponic systems, which range from 5 to 10% of the total cost of production (Shumet Afrassie, 2023) and this forms the main obstacles for the growth of hydroponics in Ethiopia (Tyson *et al.*, 2011). Despite these restrictions, the majority of Ethiopians choose to purchase high-quality, hygienic food products at reasonable prices; therefore, there is room for hydroponic farm expansion (Shumet Afrassie, 2023).

2.3. Aquaponics

According to Lennard (2009), aquaponics is the blending of two distinct agricultural techniques: hydroponic plant farming and recirculating fish aquaculture. This indicates that it is a man-made habitat that is used to raise fish and plants and depends on symbiotic relationships between the fish, plants, and bacteria (Lennard, 2009). The combination of these systems—aquaculture and hydroponics—manages the removal of nutrients, mostly nitrates and phosphates, which are

hazardous to fish. This reduces the need for water change and, as a result, helps in preserving pollution free water (Lennard, 2009).

According to Rakocy *et al.* (2006), nutrients from fish culture systems that are dissolved must be comparable to those required by the hydroponic system's flora. The transportation of nutrient-rich waste water to the plants is economical and environmentally responsible in aquaponics (Rakocy and Nair, 1987). As a result, it is a sustainable technology that allows for increased production per square meter as resources become scarce (Rakocy and Nair, 1987).

A good and effective method of filtration is the removal of nutrients from fish effluent by plant nutrient absorption (McMurtry *et al.*, 1990). With the specified inputs (feed) and outputs (fish, plants, and particulate matter), the system's nutrient levels can be stabilized (Rakocy *et al.*, 2006). The goal of an aquaponics system is to keep the nutrients in a particular system in balance to prevent an excess of nutrients, particularly nitrogen (Rakocy *et al.*, 2006). Through feed, which the fish consume, digest, and excrete, nutrients are given to the system (Rakocy *et al.*, 2006). It is feasible to optimize resource utilization and system production by balancing the nutrients that the fish system produces with the nutrients that the plant needs (Rakocy *et al.*, 2006).

In terms of yield produced per volume of water, aquaponics is the most efficient method of producing food. It is an expanding industry with enormous capacity that uses 80% to 90% less water and 75% less electricity than mechanized agriculture (Rakocy *et al.*, 1992). The fish also offers a source of protein, which many smallholder farmers lack. Instead of using conventional agricultural methods, aquaponics can be established by combining hydroponic plant culture and fish aquaculture (Rakocy and Nair, 1987). Other types of aquaculture systems cannot generate as

many fish per liter of water as intensive RAS can (Timmons *et al.*, 2002). In fish systems, evaporation discharges, and water changes are the main causes of water loss (Chavesz *et al.*, 2000). The amount of water required to produce one kilogram of food is much less in integration of fish and plant systems (Chavesz *et al.*, 2000). In greenhouse hydroponics, water from RAS systems can be used to boost production, potentially requiring 20–27% less water than traditional agriculture (Chavesz *et al.*, 2000). Crop output from aquaponic systems can be on par with that from hydroponic systems (Sabidov, 2004).

Aquaponics technology has advanced over time, from small backyard enthusiast systems to massive automated commercial setups located in greenhouses (Johanna *et al.*, 2016). Based on development and production intensity, aquaponics systems can be divided into conventional and commercial types (Johanna *et al.*, 2016). The fish compartment, plant compartment, biofilters, and sump containers are the essential components of conventional aquaponics systems (Johanna *et al.*, 2016).

Advanced aquaponic systems must take into account all technical advancements, including fish tank design, biofilter layout, sterilizing modalities, hydraulic loading rate, hydraulic retention duration, nutrient quality, and even biosafety concerns (Love *et al.*, 2015). Following technical developments in the industry, commercial-scale aquaponics systems recently began in a number of locations, including Africa (Love *et al.*, 2015).

Aquaponics faces several technical and financial challenges despite its ability to be a crucial protein and nutrition production system with very little environmental difficulty and infrequent water consumption performance (Goddek *et al.*, 2015). Due to technological demand,

aquaponics is currently seen as a less advantageous agricultural prospect than aquaculture and hydroponics (Goddek *et al.*, 2015) .

2.3.1. Types of aquaponics systems

2.3.1.1. Media filled bed

Media-filled beds use containers filled with gravel, perlite, or another medium to support the plant and are the easiest to build and maintain Bernstein (2014). Water from the fish aquarium is pumped into the media beds where the plants are grown, and it is then flow back into the fish tank. The grow bed, according to Bernstein (2014) and Somerville *et al.* (2014), is the structure that will act as the basis for the development of the plants. The width and depth of the bed will determine how many plants, how much growing media can be used as a growing medium, and how much water can be used in the garden. (<https://farmingaquaponics.com/media-bed-aquaponics/>).

One benefit of media bed aquaponics is the flexibility in choosing different physical media types to use in the grow bed Bernstein (2014). When assessing material choices, some elements should be taken into account to increase the likelihood of a successful garden Bernstein (2014). Here are a few examples: Has a pH that is balanced, maintains a sizable surface area to support bacterial growth, doesn't absorb harmful substances to prevent changing the quality of the water, simple to handle, costs little to nothing to aerate, has excellent drainage capabilities to reduce system clogging, and is light weight to prevent adding additional stress to the grow bed (<https://farmingaquaponics.com/media-bed-aquaponics/>).



Figure 1. Media bed unit (Somerville *et al.*, 2014)

In particular, the ability of the system to support a lot of beneficial bacteria and the decomposition of nutrients, which produce higher amounts of potassium and phosphorous that fruiting flowers require (Bernstein, 2014), are the advantages of media beds that other aquaponics systems lack.

The inability to harvest complete plants due to plant roots tangled in the gravel medium is one of the drawbacks of media beds (Bernstein, 2014). Large plants like tomatoes need the structure and high nutrient profile offered by media beds, whereas frequently harvested items like lettuce are best produced in different structures (Bernstein, 2014).

2.3.1.2. Nutrient Film Technique

Systems using the nutrient film method (NFT) are made of horizontal pipes with perforations about every foot for planting plants (Bernstein, 2014). The plant roots hold onto and absorb nutrients from the thin film of water that travels down the pipe as the nutrient-rich water trickles down the pipes (Bernstein, 2014). To lessen the amount of space needed, the system can alternatively be oriented vertically (Bernstein, 2014). In this technique, plants absorb nutrients at the same time that water enters the PVC pipe. For small plants with a modest nutritional requirement, like lettuce, this technique is unquestionably most suitable and acceptable (Bernstein, 2014).

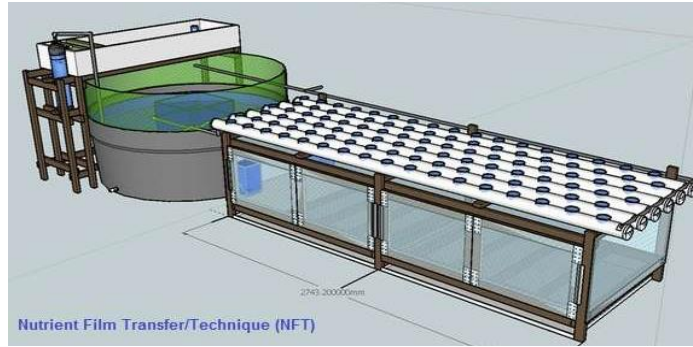


Figure 2. Nutrient Film Technique (NFT) (Somerville *et al.*, 2014)

The nutrient film method offers advantages of its own. Some advantages include being the ideal way to use on rooftops, being pleasant for herbs and leafy green vegetables, having a little water requirement for the plants, being able to harvest the vegetation plainly, and taking up less space (Liyuwork, 2018).

The drawbacks of nutrient film techniques are as follows: Only short plants are easily supported by the system when using filtration methods and huge water extents will raise humidity and cause fungal disease (Liyuwork, 2018). If the nutritional solution flow is interrupted, the roots will quickly dry out and become stressed. The roots of vigorously developing plants can obstruct pathways, and crop death can occur quickly in hot weather due to pump failure (<https://www.agrifarming.in/nft-farming-in-india-nft-advantages-disadvantages>).

2.3.1.3. Raft system (Deep water culture)

Productions on a small to large scale employ deep-water culture. The plants are positioned on floating rafts, with their roots dangling in the nutrient-rich water. Through a biofilter, the fish tank provides nutrient-rich water (Thorarinsdottir *et al.*, 2015). After the nutrients are utilized by the plants, the water is cleaned and returned to the fish tank (Liyuwork, 2018). Due to its ability to produce enormous amounts of plant life in a very small area and the ease of harvest due to the

roots' lack of attachment to anything, this approach is most frequently used by commercial farmers (Bernstein, 2014).

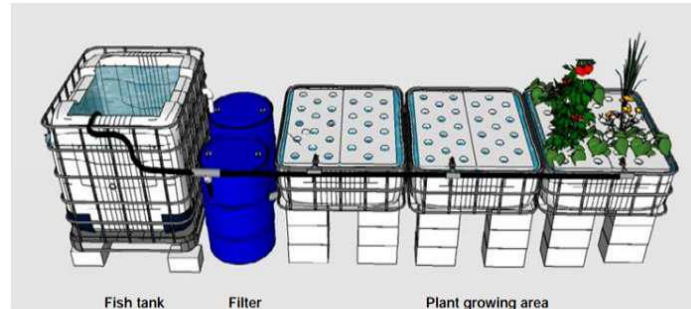


Figure 3. Raft system of aquaponics (Somerville *et al.*, 2014).

The practice of deep-water culture has some benefits. These benefits include the ability to grow any kind of plant, even tall, fruiting plants, on this system (Liyuwork, 2018). In comparison to previous systems, it uses noticeably less electrical energy, and the medium is also easily able to absorb and mineralize solids (Liyuwork, 2018). Deep water culture has the disadvantages that media may be expensive, may not be available, and occupy space (Liyuwork, 2018).

2.4. The Bio filter

For an aquaponic system to operate properly, nitrifying bacteria are essential. Both the microorganisms that oxidize ammonia and nitrite are present (FAO, 2014). Nitrite is converted to nitrate by nitrite-oxidizing bacteria, and ammonia is converted to nitrite by ammonia-oxidizing bacteria (FAO, 2014). The most prevalent ammonia-oxidizing bacteria in aquaponics belong to the genus *Nitrosomonas*, while the most prevalent nitrite-oxidizing bacteria belong to the genus *Nitrobacter* (FAO, 2014). The bacteria are absolutely essential to the aquaponic ecology. Ammonia concentrations in the water will kill the fish if the bacteria aren't there or aren't working well. In order to keep ammonia levels close to zero, it is crucial to maintain and manage a healthy bacterial colony within the system (FAO, 2014).

Even in the air, the bacteria can be detected, but they require a surface to survive. After being blasted into the system, they will begin to reproduce once their food is present (Spencer, 2018). This establishing process requires time, and in recently started systems, the fish may be producing ammonia more quickly than the bacteria can handle (Spencer, 2018). This is why it is crucial to integrate new systems gradually and give the bacteria enough time to multiply to handle the ammonia produced when the system is working at full capacity (Spencer, 2018).

2.5. Aeration

By injecting air into the water, aeration increases the amount of dissolved oxygen in the solution. According to www.water-research.net/index.php/dissolved-oxygen-in-water, fish need 4 to 5 milligrams of dissolved oxygen per liter of water on average. The key is that smaller bubbles must form further into the tank. Because the bubbles are rising from a deeper level, they can be absorbed more quickly, and the water will have more time to take in the oxygen.

As the water sinks through successive layers to the bottom and degasses, the air gets oxygenated. Another method of providing water to the grow beds is via spray bars, which allow smaller volumes of water to fall into the beds and create bubbles. One kind of mechanical aeration device that can be utilized is a propeller; however, they are often more expensive and less common. Any method that includes splashing water introduces bubbles and, consequently, oxygen (www.water-research.net/index.php/dissolved-oxygen-in-water).

2.6. Clarification

The process of clarification is utilized to remove solid waste from water that is being passed from fish to plants. The solid waste could clog the system's pipes and trigger a catastrophic breakdown if it is not eliminated. Depending on the clarifying method being used, heterotrophic bacteria may be added, which would break down the waste's solids (Somerville *et al.*, 2014).

Even if the bacteria were present and no additional clarifying was used, there would still be too much waste to break down, necessitating the installation of a separate chamber to deal with the solid waste. This task can be accomplished in a variety of ways (Somerville *et al.*, 2014). Because they are easy to construct, swirl filters are often utilized. Water enters a spherical barrel at these spots at an angle that is almost perpendicular to the barrel's curvature (Somerville *et al.*, 2014). A weak vortex effect is subsequently produced, which pulls the solid waste to the water's bottom. The cleaned water then exits the barrel (Somerville *et al.*, 2014).

2.7. Fish species reared in aquaponics systems

Traditional farmed fish species can be adapted to aquaponics systems as well. It is possible to set up aquaponic systems in freshwater, marine, and brackish water habitats. According to Lennard and Goddek (2019), the majority of cultivated fish species can handle crowding, which is a favorable phenomenon for aquaponics systems. As a result, aquaponics systems may effectively cultivate a distinct kind of fish (Bich *et al.*, 2020). In aquaponics systems, several freshwater fish species that can endure crowding do pretty well (Oliveira *et al.*, 2020). Tilapia, trout, perch, Arctic char, and bass are a few examples of fish that have been successfully adapted to the recirculating aquaculture system (RAS). There is a high number of studies that have cultured various fish species in aquaponics, including Nile tilapia (*Oreochromis niloticus*) (Babatunde *et al.*, 2019), African catfish (*Clarias gariepinus*), Arctic char (*Salvelinus alpinus*), Koi carp (*Cyprinus carpio*) (Paudel, 2020), pikeperch (*Stizostedion lucioperca*), Atlantic salmon (*Salmo salar*), Asian sea bass barramundi (*Lates calcarifer*), sturgeon (*Order acipenseriformes*), rainbow trout (*Oncorhynchus mykiss*), eu eel (*Anguilla anguilla*), and largemouth bass (*Micropterus salmoides*) (Fronte *et al.*, 2019).

The majority of the data available for fish for the overall performance in aquaponics is based on tilapia production, despite the diversity of fish species produced in aquaponics under both small-scale and large-scale (commercial) aquaponics (Endut *et al.*, 2016). Tilapia is one of the most frequently cultivated fish globally, accounting for more than 75% of global fish production (FAO, 2019), and its production has been increasing tremendously in recent years.

According to Palm *et al.* (2014), Nile tilapia can be successfully cultivated with cucumber (*Cucumis sativus*) and lettuce (*Lactuca sativa*), yielding an average harvestable weight of up to 500 g in significantly less time than a year. Growing Nile tilapia beside parsley (*Petroselinum crispum*) and basil (*Ocimum basilicum*) leads to better growth. Several fish species, including channel catfish, rainbow trout, common carp, koi carp, goldfish, Asian sea bass (Barramundi), and Murray cod, have shown significant growth in some studies when grown in trial aquaponic systems (Shete *et al.*, 2013). The success of an aquaponics system has been found to depend on the fish's overall performance in terms of weight increase, food conversion, yield, survival, and biomass, as well as on a number of management techniques used in aquaponics (Maucieri *et al.*, 2019).

2.8. Feeding Fish in an Aquaponics System

Aquaponics systems are a fantastic way to raise fish and cultivate plants in a mutually beneficial setting (Sharad *et al.*, 2015). However, feeding fish in an aquaponic system might be difficult. Commercial fish feed is often well received by fish. Their diets must have a healthy balance of carbohydrates, proteins, fats, vitamins, and minerals (Sharad *et al.*, 2015). These items are regularly used in expertly prepared fish diets. In addition to worms, which are high in protein, some wild fish may also eat algae, which is low in protein. Small-scale aquaponic farmers can

choose from a number of these ingredients to feed their fish, although using commercial feed pellets will promote the fastest growth in tilapia (Sharad *et al.*, 2015).

The most popular option for an aquaponics system is fortified fish pellets because of their simplicity of use and comprehensive nutritional profile (Sharad *et al.*, 2015). However, there are numerous alternate food sources, including duckweed, soy meal, and soldier fly larvae that do not contain fishmeal and have the proper amounts of protein. Running an aquaponics system will be easier if fish are fed the best food in the right quantities, which will also maintain the ecosystem's stability (Sharad *et al.*, 2015). Almost all fish species eat fish pellets in some form or another. Others, like the tilapia, are herbivores and would instead eat plants. Some species, like largemouth bass, prefer to eat smaller fish. (<https://smallscalegardener.com/feeding-fish-aquaponic>).

2.9. Water quality parameters of aquaponics system

Since water quality metrics are of key value in hazard detection for the welfare risk assessment of various aquaculture activities, aquaponics systems are not distinct from aquaculture (Evans *et al.*, 2000). Aquaponic fish farming requires clean water; thus, the water quality criteria must fall within each species' permissible tolerances (Evans *et al.*, 2000). Regular evaluation of those critical water quality indicators is essential because abrupt changes in fish stocking density, growth rate, feeding rate, or water volume may cause rapid changes in water quality (Evans *et al.*, 2000). Declining water quality indicators have an effect on fish physiology, development rate, and feed efficiency, which can lead to pathological changes and even mortality in extreme circumstances (Evans *et al.*, 2000).

When considering fish welfare issues and maintaining the demands of plants and fish in a co-culture medium in aquaponics systems, carrying capacity is essential. Carrying capacity is a

measure of the system's maximal fish biomass that still complies with acceptable water quality criteria (Evans *et al.*, 2000) . The carrying capacity of a specific volume of water is determined by the rate of oxygen consumption by fish as well as how they respond to ammonia, CO₂, and other potentially dangerous metabolic wastes produced by the environment (www.water-research.net/index.php/dissolved-oxygen-in-water).

Water is the only source on which fish can carry out all of their basic functions. Physical, chemical, and biological components interact both collectively and individually in aquaculture habitats to affect culture performance (Schmittou, 2006). Ammonia and urine are excreted by the fish into the water column. Due to the buildup of uneaten food, the ammonia level will rise. Ammonia quickly builds up and gathers in the water during protein digestion, adversely impairing the fish's ability to thrive (Nichols and Savidov, 2011). Numerous studies have demonstrated that a combination of plants and microorganisms may effectively remove or convert ammonia from fish water, maintaining wholesome living conditions for both fish and plants (Nichols and Savidov, 2011). Temperature, dissolved oxygen (DO), and hydrogen ion concentration (pH) are the important water quality parameters in relation to the culture of *Oreochromis niloticus* and other fish species. However, other factors, like alkalinity, hardness, phosphates, nitrates, and ammonia, also have a big impact on those ecosystems (Abolude *et al.*, 2012).

2.9.1. Temperature

Since fish often assume the same temperature as their surroundings, temperature is one of the most significant environmental factors and a significant metabolic modulator in fish. It affects their movement, mannerisms, feeding, development, survival, procreation, and food conversion effectiveness (Handeland *et al.*, 2008). Two main effects of temperature on tilapia cultivation are

the temperature of the water in which the fish are found and the stratification of temperatures in the water column in which the fish reside (Schmittou, 2006).

Water temperature affects all aspects of aquaponics systems. It affects not only what type of fish can be reared, but, plant growth and the performance of the biofilter. Temperature has an impact on DO as well as on the toxicity (ionization) of ammonia; excessive temperatures have less DO and more unionized (poisonous) ammonia (FAO, 2003). Fish species are temperature-dependent. Warm-water species choose temperatures ranging from 18°C to 29°C, while cold-water species, including trout, thrive at temperatures in the range of 13°C to 18°C (Resh, 2001). Tilapia is a warm-water fish in that it prefers temperatures of 27–29 °c for maximum growth. But it can resist some low-level temperature ranges. When the water temperature drops below 21°C, growth slows dramatically, reproduction stops, and the incidence of disease increases (Tyson *et al.*, 2007). The optimum temperature for the proper growth of lettuce is 16–25°C. The temperature for maximum growth of nitrifying bacteria is 25–30°C. And the growth rate of bacteria is reduced while the temperature is less than 18°C (Licamele, 2009).

2.9.2. Dissolved Oxygen

Dissolved oxygen is the most essential parameter for the growth of fish and plants, and it is also very essential to nitrifying bacteria (Lennard, 2009). It requires continuous monitoring of tilapia culture systems. Low levels of dissolved oxygen are critical to *Oreochromis niloticus* culture and are responsible for massive fish kills, either directly or indirectly, in comparison to all other problems combined (Lennard, 2009). *Oreochromis niloticus* grows properly at DO ranges greater than 3mg/l, while lettuce will grow satisfactorily at a DO degree of at least 4 ppm. Oxygen clearly enters and dissolves in the water through diffusion at the air-water interface and

oxygen-releasing photosynthesis (Schmittou, 2006). Diffusion is relatively insignificant unless there is considerable wind action. Low dissolved oxygen is associated with an increase in ammonia, an increase in free carbon dioxide, decreased pH, increased nitrite, increased fish metabolism, increased water temperature, abundant gill parasites, and many other elements that, when combined, can appreciably reduce fish production (Schmittou, 2006).

The DO degree describes the amount of molecular oxygen in the water, and it is measured in milligrams per liter. It has the most immediate and drastic impact on aquaponics (Lennard, 2009). Certainly, fish may die within hours when exposed to low DO within the fish tanks. As a result, ensuring adequate DO levels is important to aquaponics (FAO, 2003). The optimum DO levels for each organism-fish, lettuce, and nitrifying bacteria to thrive are 5–8 mg/liter (Lennard, 2009).

The concentration of dissolved oxygen should not be below 2 mg/l to culture fish for their performance, and nitrification will not occur if concentrations drop to 2.0 mg/l (ppm) or less (Licamele, 2009). Tilapia is oxygen-tolerant, and it may live in lower degrees of DO, but its growth rate will be affected. If the level of DO decreases in the tank, it will come to the surface for oxygen-rich water. DO levels are related to temperature, and this indicates warm water holds less oxygen (Yoshida *et al.*, 1997).

2 9.3. pH

Water acidity (pH) is referred to as the master variable in aquaponics as it influences many water quality parameters, including % NH₃ vs. % NH₄⁺ as well as the solubility of different plant nutrients, which influences both fish and plants (Rakocy *et al.*, 2004). The acceptable range for fish culture is usually between pH 6.5 and pH 9.0. When water is very alkaline (>pH 9), the

ammonia in the water is toxic and can kill fish. On the other hand, acidic water leeches metals from rocks and sediments (and solid substrates in grow beds) (Rakocy *et al.*, 2004). These metals have an adverse impact on the fish's metabolism rates and ability to take in water via their gills, and they can be fatal as well (Lawson, 1995). Aquaculture pH guidelines for warm-water fish suggest that pH 4.0 is the acid death point; pH 4.0–5.0 is no production; pH 6.5–9.0 is a desirable range for fish production; pH 9.0–11.0 gives slow growth; and pH > 11.0 is the alkaline death point (Lawson, 1995). Importantly, different fish species can be more tolerant of changes in pH. For instance, tilapia can tolerate a wide pH range, 5.0–10.0, but different species may not (Rakocy *et al.*, 2004).

2.9.4. Ammonia

Nitrogen is the fourth important water quality parameter. It's required by all life and is part of all proteins. Nitrogen enters an aquaponics system from the fish feed, usually labeled as crude protein and measured as a percent (Lawson, 1995). Some of this protein is used by the fish for growth, and the remainder is released by the fish as waste. This waste is, in most cases, in the form of ammonia (NH_3) and is released through the gills and as urine (Lawson, 1995). Solid waste is also released, some of which is converted into ammonia through microbial activity. This ammonia is then nitrified by bacteria and converted into nitrite (NO_2) and nitrate (NO_3). Nitrogenous wastes are toxic to fish at certain concentrations, despite the fact that ammonia and nitrite are approximately one hundred times more toxic than nitrate (FAO, 2014). Even though they are poisonous to fish, nitrogen compounds are nutritious for flora and are indeed the primary element of plant fertilizers. All three varieties of nitrogen (NH_3 , NO_2 , and NO_3) may be used by vegetation; however, nitrate is the most accessible (FAO, 2014). In a fully functioning aquaponics unit with adequate biofiltration, ammonia and nitrite levels have to be close to 0, or

at a maximum of 0.25–1.0 mg/liter. The bacteria present in the biofilter have to convert nearly all of the ammonia and nitrite into nitrate before any accumulation can occur (FAO, 2014).

3. MATERIALS AND METHODS

3.1. Description of study area

The Batu Fish and Other Aquatic Life Research Center (BFOALRC), administered by the Oromia Agricultural Research Institute in Ethiopia, conducted the study. The center is located 163 kilometers southeast of Addis Ababa, Ethiopia's capital, in the East Shoa administrative Zone of Oromia Region, at 7°9'N latitude and 37°7'E longitude, at an elevation of 1,638 meters above sea level in the Ethiopian Central Rift Valley.

One of Ethiopia's fisheries centers, BFOALRC focuses on aquaculture research, including aquaponics, recirculating aquaculture systems, and integrated aquaculture. Other research areas include fishery biology, fishing and processing technology, and lake and reservoir limnology.

BFOALRC is also active in community service, distributing fingerlings to remote areas of Oromia and other parts of Ethiopia for production and research, and stocking fingerlings for model farms. It also hosts postgraduate students from various Ethiopian universities and provides them with facilities and technical support for their MSc and PhD theses.

3.2. Experimental design and set up

The experiment was carried out in an existing recirculating aquaponics system located at the Batu Fish and Other Aquatic Life Research Center. The study was performed from March to May 2023 (12weeks). The experiment was conducted in a completely randomized design with four treatments and three replicates per treatment. The treatments were: (1) media bed with tomato, (2) media bed with lettuce, (3) NFT with tomato, and (4) NFT with lettuce.

Four independent concrete rectangular fish tanks with a 2000-liter capacity each were used in this experiment. Two of the tanks were connected to separate media field beds, and the other two fish tanks were connected to separate NFT systems; the four tanks were arranged in a row alternatively. Water recirculates between the fish tanks and the plant beds with the aid of water pumps.

Fingerlings of Nile tilapia (*Oreochromis niloticus*, L.1758), mixed sex, belonging to same size were collected from the Batu Fish and Other Aquatic Life Research Center. The initial total length and weight of the fingerlings were 11cm and 20g respectively. The fingerlings were acclimatized by adding the water of small amount from the aquaponic system again and again to the water from the pond where they found earlier in small sized plastic container. 100 fish were stocked in each experimental fish tank.

Tomato (*Solanum lycopersicum*) and Lettuce (*Lactuca sativa*) were selected for the experiment and the seeds were purchased from Batu local market. The seedlings of tomato and lettuce were germinated on prepared beds in the center's vegetable garden and watered from the aquaponics system one week prior to transplanting. Each seedling of tomato and lettuce was placed into a perforated plastic cup filled with gravel substrate, which was in turn placed within the grow pipe in the nutrient film technique or planted on the gravel media in the media bed system.

Water pumps were used to elevate water from fish tanks to MB or bio-filter units in the NFT system, where bacteria convert fish waste (ammonia) to available nutrient forms (nitrite and nitrate) for plant uptake in the MB and NFT, after which the water flows back to the fish tank through pipes by gravity force.

Fish were supplied twice a day with commercial feed made by quality feeds with an average protein content of 30%. Throughout the experimental period, the daily feeding ratio was maintained at 3% of fish biomass per pond. A random sample of Nile tilapia individuals per treatment was sampled monthly for length and weight measurements. The mortality of fish was monitored daily.

3.3. Preparation of media bed unit and nutrient film technique

A media bed of square shape with 1m width, 1 m length and 30cm depth was constructed and duplicated. Volcanic gravel (tuff) was used as a medium. The nutrient film technique was constructed with three pipes of a size of 6m length and 11cm diameter. Each pipe was with holes of 7cm diameter and was duplicated.

3.4. Data collection

3.4.1. Monitoring water quality

The water quality parameters of fish-growing ponds were monitored fortnightly during the study period. Data on dissolved oxygen (DO) concentration, pH, temperature, TDS, conductivity, and salinity were determined and recorded every two weeks and three times per sampling date from the pond, pipe, bed and biofilter. The parameters were determined at 8:00 pm, 12:00pm, and 4:00 am insitu. Dissolved oxygen (DO) concentration, pH, temperature ($^{\circ}\text{C}$), conductivity (mS), and salinity (ppt) were measured using a Hanna multimeter (HI9829 model) at the experimental site. The TDS of the water was measured by a turbidimeter (the Thermo Scientific Eutech – 100 waterproof turbidimeter made in Singapore). These parameters were selected because they highly affect the growth and yield of fish and vegetables if they are out of range. New water was added if these parameters were out of range. The water lost through transpiration, evaporation, and periodic flushing was replaced weekly. Mean \pm (SE) for all water quality parameters were calculated per treatment.

3.4.2. Fish sampling

The fish in all ponds were randomly sampled at the end of every month in the morning from the ponds using a scoop net (1 mm mesh size). Thirty live fish were randomly scooped out of each

pond unit. Their total length (TL) and individual live body weights were measured using a measuring board and a sensitive balance (SKX2201 Max = 2200 g, d = 0.1 g), respectively.

3.4.3. Tilapia survival rate

Daily fish mortalities were recorded during the experimental period. At the end of the culture period, all the ponds were emptied, and the number of fish in each pond was determined. The percentage survival rate was calculated as: Survival Rate (%) = [Number of fish at harvest / Total number of fish stocked] × 100 (Mohammed *et al.*, 2003).

3.4.4. Tilapia condition factor

The condition factor of each fish was measured using the following equation:

$$K = 100 (TW/TL^3) \text{ (Lagler, 1956)}$$

Where, K = Fulton's condition factor

TW = total weight in grams,

TL = total length in centimeter

3.4.5. Growth performances of Tilapia

Growth performance of Nile tilapia was determined by Fish Mean Total Length (FMTL), Fish Mean Body Weight (FMBW), Mean Body Weight gain (MBWG) and Food Conversion Ratio (FCR) as described below.

3.4.5.1 Fish Mean Total Length

$$FMTL = L_t - L_0 \text{ (Eri } et al., 2018)$$

Where: FMTL = Fish mean total length

L_t = length average of individual at day t (cm)

Lo = length average of individual at initial day/day 0 (cm)

3.4.5.2 Fish Mean Body Weight

FMBW= $W_t - W_o$ (Eri *et al.*, 2018)

Where: FMBW = Fish Mean Body Weight

W_t = Weight average of individual at day t (g)

W_o = Weight average of individual at initial day (g)

3.4.5.3 Mean Body Weight Gain of Tilapia

The Mean Body weight gain of Nile tilapia was calculated by the following formula:

Mean Body Weight Gain (g) = $W_f - W_i$

W_i and W_f are the initial and final mean body weights respectively (Mohammed *et al.*, 2003).

3.4.5.4 Food Conversion Ratio

The food conversion ratio of Nile tilapia was calculated by the following formula (Osofero *et al.*, 2009).

Food Conversion Ratio (FCR)= $\frac{\text{Total feed intake by fish (g)}}{\text{Total weight gain by fish (g)}}$

3.4.6 Growth and yield measurements of tomato and lettuce

Growth measurement of tomato and lettuce was done by the following procedures: The height of the plant was measured using a ruler at the morning. The number of leaves for each plant was counted to including the tips of newly emerging leaves at the morning. The plant samples were divided into leaf, stem, and root and weighted using the Sensetive balance LD210-2, Max = 210 g, d = 0.01 g. Total leaf area was measured using a leaf area meter (LiCor LI-3100C) at the harvest stage. The leaves were cut off from the stem and entered into the leaf area meter, and the

reading was shown on the screen and recorded in square centimeters (cm²). Growth rate of the tomato and lettuce was calculated by the following formula:

$$\text{Growth rate} = \frac{\text{Height of plants (cm)}}{\text{Culture period (days)}}$$

To measure the yield, the number of punches per plant was counted, and the number of tomato fruits per punch was counted. For lettuce, the yield is its leaf; the leaves were collected from each plant, and the fresh yields of the tomato (Salam *et al.*, 2014) and lettuce were measured at harvest.

3.5. Data Analysis

All the data collected during the experiment were arranged and summarized in an Excel sheet. An analysis of variance was performed using SPSS version 25 with a 95 percent confidence interval to compare the statistical significance among each treatment.

4. RESULTS AND DISCUSSION

4.1 Water Quality

Table 1. Water quality parameters of pond (A), pipe (B) of a MB and NFT, and Bed from MB and the Biofilter of NFT (C) of the Aquaponics systems

Parameter	Section	Mean + standard Error		P – value
		MP (n = 72)	NFT (n = 72)	
pH	A	9.32±0.01	9.41±0.01	0.945
	B	9.26±0.01	9.42±0.01	0.065
	C	9.28±0.1	9.45±0.01	0.067
Temperature(°c)	A	24.63±0.1	25.58±0.12	0.725
	B	25.36±0.12	25.7±0.15	0.085
	C	25.7±0.14	25.4±0.13	0.112
TDS(g/l)	A	1.76±0.03	1.77±0.04	0.863
	B	1.75±0.03	1.76±0.04	0.860
	C	1.77±0.03	1.76±0.04	0.839
Conductivity(mS)	A	2.40±0.45	2.40±0.05	0.847
	B	2.30±0.04	2.38±0.05	0.873
	C	2.40±0.42	2.38±0.04	0.872
Salinity(ppt)	A	1.22±0.02	1.30±0.04	0.072
	B	1.21±0.02	1.29±0.02	0.820
	C	1.22±0.02	1.21±0.02	0.763

Table 1 shows the physicochemical parameters of the culture systems in the media bed (MB) and nutrient film technique (NFT) aquaponics. The pH ranged between 9.26 and 9.45, which is slightly above the optimal range of 6.5 to 9.0 for fish culture (Lawson, 1995). This might be due to the saline nature of the source water in the study area. The temperature ranged between 24.63°C and 25.7°C, which is within the suitable range of 18°C to 29°C for warm-water fish species (Resh, 2001). The total dissolved solids (TDS) ranged between 1.75 g/L and 1.77 g/L, the conductivity ranged between 2.3 mS and 2.4 mS, and the salinity ranged between 1.21 ppt and 1.3 ppt. These parameters indicate the amount of dissolved salts and minerals in the water, which can affect the osmoregulation and metabolism of fish (Timmons *et al.*, 2002). The results show that there was no significant difference in the water quality parameters between the MB and NFT aquaponics systems, implying that the type of aquaponics system did not affect the

water quality. This is consistent with the findings of (Rakocy *et al.*, 2006), who reported similar water quality parameters in different types of aquaponics systems. However, the results of the current study differ from some previous studies that reported lower or higher values of pH, temperature, and other parameters in aquaponics systems using different fish and plant species (James *et al.*, 2014); (Philipe, 2020); (Eri *et al.*, 2018); (Ritty *et al.*, 2021); (Trang *et al.*, 2017); (Rita *et al.*, 2021); (Wilson *et al.*, 2006); (Sunday *et al.*, 2020); (Jung and Yew, 2013). These differences might be due to the variations in the source water, climatic conditions, system design, and management practices of the aquaponics systems.

The ammonia-oxidizing bacteria and nitrite-oxidizing bacteria present in the filter media of the aquaponics system may be responsible for the greater levels of NO₃ and lower levels of harmful ammonia in the enhanced environmental conditions in the aquaponics system.

In the media-filled bed aquaponics system, the amount of nitrite nitrogen in the pond was 109.08mg/l; in the pipe, it was 22.67mg/l. But there was a difference in nitrite concentration in the bed of two replicates of the media-filled bed system. In the first bed, the nitrite concentration was 3.74mg/l, and in the second bed, the nitrite concentration was 54.16mg/l. This might be because of the type of system, i.e., in the current study, the media-filled bed system was designed as ebb and flow. The water first enters the bed and fills it slowly, and after the water is filled in the bed part of the media-filled bed system, the water begins to flow slowly to the pond through the pipe. According to the result of the current study, the difference in nitrite concentration in the bed part of the media-filled bed system is that in the first bed, the water sample was taken after the bacteria did the nitrification process and converted the nitrite into nitrate, and in the second

bed, the water sample was taken before the bacteria converted the nitrite into nitrate, i.e., if the water entered the bed from the pond.

In the media-filled bed system of an aquaponics system, the amount of nitrate-nitrogen concentration in the pond was 21.71mg/l, in the pipe it was 23.57mg/l, and in the bed it was 28.05mg/l. This implies that the nitrifying bacteria were active and converted nitrite to nitrate effectively because the amount of nitrate in the bed was higher than the amount of nitrate in the pond. The amounts of nitrate in the pipe and bed were different from each other, and the amount of nitrate in the bed was higher than the amount of nitrate in the pipe. This implies the nitrifying bacteria converted nitrite to nitrate, and plants on the bed uptake the nitrate as their feed.

In the NFT of the aquaponics system, the amount of nitrate-nitrogen concentration in the pond was 10.44mg/l, in the pipe it was 11.47mg/l, and in the bio filter it was 17.93mg/l. This implies that the nitrifying bacteria were active and converted nitrite to nitrate in the biofilter. The amount of nitrate in the biofilter was higher than the amount of nitrate in the pipe. This implies that plants uptake nitrate as their feed.

Most of the values for water quality recorded in the present study were similar (with no significant difference) ($P > 0.05$) when water from the different parts of the system was compared. Maucieri *et al.* (2017), similarly observed insignificant differences. In order to determine precisely where nutrients are retained and what percentage is recycled or lost, it is crucial to be aware of the nutrient mass balances in an aquaponics system (Delaide *et al.*, 2017).

Microbial communities play a crucial role in the nutrient dynamics of aquaponics systems by converting ammonium to nitrate and facilitating the processing of both dissolved and particulate waste (Bittsanszky *et al.*, 2016). Only a small part of the nitrogen and phosphorus normally

removed from the water is taken up by plants; this shows that microbial processes in the root zone and the substrate the plant was propagated on have a substantial impact on this (Trang and Brix, 2014).

4.2 Survival, condition factors and growth performances of Nile tilapia

The survival rate (SR), condition factor (CF), final mean total length (FMTL), final mean body weight (FMBW), mean body weight gain (MBWG), and food conversion ratio (FCR) of Nile tilapia reared in the media-filled bed (MB) and nutrient film technique (NFT) of aquaponics systems are presented in Table 2. The results showed that there was no significant difference ($P > 0.05$) between the fish reared in the two treatment systems for all growth parameter measurements. This indicates that the MB and NFT of the aquaponics system did not affect the survival, condition factor, or growth performance of Nile tilapia. The survival rate is the percentage of fish that survived from the beginning until the end of the experiment. The survival rate of the current study was high and similar between treatments, which suggests that the water quality in the fish culture medium was suitable for the fish. Aquaponics systems are efficient in providing optimal water conditions in terms of feed utilization, nitrification process, and dissolved oxygen levels, which ensure the water quality in all of the treatments. The nitrification process converts ammonia to nitrate with the help of beneficial bacteria. Nitrate is not harmful to fish, so the fish survival rates are good. However, if the water quality is poor, it can cause the formation of non-ionized ammonia, or NH_3 , which is toxic to fish and can result in death. This can happen if the fish are stressed by poor water quality, which reduces their appetite and prevents them from properly digesting the feed that is provided. The fish's respiratory system is also affected by the availability of oxygen. Low oxygen levels in water can cause stress and mortality in fish. The survival rate of Nile tilapia in the current study is comparable to the

survival rates reported by other studies that cultured Nile tilapia with vegetables in aquaponics systems (Rahmatullah et al., 2010; James et al., 2003; Harry et al., 2014; Yuli et al., 2021). Philipe (2020) reported a slightly lower survival rate of Nile tilapia in a gravel-bed aquaponics system with lettuce, watercress, and arugula. Rita et al. (2021) also reported a low mortality rate of Nile tilapia in an aquaponics system with basil and mint, which is consistent with the current study. The mortality rate may be influenced by the stress during stocking and acclimation of the fish to the new environment, as well as the fish species, feed quality, and management practices. The current study found that the K values of *O. niloticus* in both treatments were greater than 1, indicating good fish health condition and isometric growth, which is desirable in fish farming (Ayode, 2011). This suggests that both the media-filled bed aquaponics system and the NFT of the aquaponics system are suitable for the production of *O. niloticus*. A similar result was reported by Kambegna et al. (2014), who studied *O. niloticus* at Kegati Aquaculture Research Station, Kenya, and found that the mean condition factor (K) for males and females was 1.02 ± 0.04 and 1.12 ± 0.02 , respectively. Olurin and Aderibigbe (2006) also reported that the condition factor of juvenile *Oreochromis niloticus* was 1.14 for males and 1.08 for females.

The mean final body weight of Nile tilapia in the current study, which was 60.36 ± 0.19 g and 60.67 ± 0.3 g for the media-filled bed system and nutrient film technique respectively, was lower than the mean final body weight reported by Hijaran and Suleyman (2017), who studied Nile tilapia and tomato in the classical aquaponics systems. They reported that the mean final body weight of Nile tilapia was 589 ± 58.4 g, 918.4 ± 31.8 g, and 1073.4 ± 3.18 g for the three treatments. This might be due to the differences in the initial mean body weight, the protein content of the feed, and the culturing period between the two studies. Similarly, the FMBW and FMTL of the current study were smaller than those reported by Ritty et al. (2021), who studied the growth of

Nile tilapia in an aquaponics system for 45 days. This might also be attributed to the variation in the initial mean body weight and the initial mean total length, as well as the number of days the experiment was carried out. The MBWG of fish in the current study did not show a significant difference between the two treatments, and this might be due to the same type and amount of food given to the fish in both treatments. Rita et al. (2021) reported higher MBWG of *Oreochromis niloticus* reared on diets containing black soldier fly (*Hermetia illucens*) larvae meal than the MBWG of the current study. This might be due to the difference in the type of feed given to the Nile tilapia.

Table 2. Growth parameters of Nile tilapia in the MB and NFT of aquaponics systems in the experimental area throughout the experiment period

Growth parameters	MB n= 60	NFT n= 60	P- value
Weight gain(g/fish)	40.36± 0.19	40.67± 0.3	0.486
Food conversion ratio	1.2 ± 0.13	1.2 ± 0.06	0.845
Condition factor	2.07± 0.05	2.18± 0.3	0.082
Survival rate (%)	98.59 ± 0.4	98.68± 0.95	0.454
Initial mean total length(cm)	11.05±0.13	11.05±0.13	1.000
Initial mean body weight(g/fish)	20±0.0	20±0.0	1.000
Final mean total length(cm)	14.75± 0.3	14.1± 0.27	0.110
Final mean body weight(g/fish)	60.36± 0.19	60.67± 0.3	0.486

4.3 Growth and yield of tomato and lettuce in MB and NFT of aquaponics system

The growth parameters and yield of tomatoes and lettuce grown in two types of aquaponics systems, media bed (MB) and nutrient film technique (NFT), were compared in this study. The results are presented in Table 3 and Table 4, respectively. The results showed that Tomato growth and yield were significantly higher in MB than in NFT. All the measured parameters, such as plant height, number of leaves, weight of leaf, stem, and root, growth rate, number of punches, number of fruits, individual and total weight of fruits, and leaf area, were significantly different ($p < 0.05$) between the two systems. The MB system provided more space, support, and nutrients for the tomato plants than the NFT system, which resulted in better growth and yield.

Lettuce growth and yield were also significantly higher in MB than in NFT, except for the weight of stem. The other parameters, such as plant height, number of leaves, weight of leaf and root, growth rate, and leaf area, were significantly different ($p < 0.05$) between the two systems. The MB system offered more favorable conditions for the lettuce plants than the NFT system, which led to better growth and yield. These findings indicate that the type of aquaponics system affects the growth and yield of tomato and lettuce, and that the MB system is more suitable for these crops than the NFT system. This is consistent with previous studies that reported higher plant biomass and yield in MB systems than in NFT systems (Wilson et al., 2006; Sikawa and Yakupitiyage, 2010). The MB system has the advantages of providing more surface area for nitrification, more aeration and drainage for the plant roots, and more flexibility in choosing different types of growing media (Somerville et al., 2014). Therefore, the MB system is recommended for tomato and lettuce production in aquaponics.

Table 3. Growth performance and yield of tomatoes on a MB and the NFT of an aquaponics system

Parameters	Mean \pm standard Error				P – value
	MB	N	NFT	N	
Height of plant(cm)	89.95 \pm 1.8	20	41.17 \pm 1.3	30	0.000
No of leaf per plant	38.8 \pm 1.78	20	12.95 \pm 0.4	30	0.000
Weight of leaf(g)	121.53 \pm 9.85	20	8.79 \pm 0.4	30	0.000
Weight of stem(g)	114.3 \pm 7.97	20	7.5 \pm 0.34	30	0.035
Weight of root(g)	89.24 \pm 6.76	20	10.87 \pm 0.5	30	0.000
Growth rate(cm/days)	0.79 \pm 0.01	20	0.34 \pm 0.01	30	0.000
No of punch	7.4 \pm 0.42	20	0.00 \pm 0.00	-	0.000
No of fruit per punch	4 \pm 1.03	20	0.00 \pm 0.00	-	0.000
Individual weight of fruit(g)	144.9 \pm 25.9	20	0.00 \pm 0.00	-	0.000
Total weight of fruit(g)	968.7 \pm 55.5	20	0.00 \pm 0.00	-	0.000
Leaf area(cm ²)	797.77 \pm 0.89	20	83.67 \pm 4.5	30	0.000

Table 4. Growth performance and yield of lettuce on a MB and the NFT of an aquaponics system

Parameters	Mean \pm standard Error				P – value
	MB	N	NFT	n	
Height of plant(cm)	29.75 \pm 1.29	20	23.29 \pm 1.22	30	0.000
No of leaf per plant	23.88 \pm 0.82	20	15.25 \pm 0.19	30	0.000
Weight of leaf(g)	92.66 \pm 0.55	20	85.76 \pm 0.43	30	0.000
Weight of stem(g)	13.08 \pm 0.7	20	12.4 \pm 0.82	30	0.538
Weight of root(g)	34.79 \pm 0.64	20	8.9 \pm 0.38	30	0.000
Growth rate(cm/days)	0.62 \pm 0.03	20	0.26 \pm 0.02	30	0.000
Leaf area(cm ²)	157.95 \pm 3.79	20	61.2 \pm 1.5	30	0.000

5. CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The following conclusions are made from the present study

The media-filled bed and nutrient film techniques of aquaponics systems did not affect water quality. Survival, condition factor, and growth performance of Nile tilapia in media-filled and nutrient-film techniques of aquaponics systems were similar. Likewise media-filled beds and nutrient-film techniques of aquaponics systems did not affect the growth of fish. A media-filled bed is more suitable for the growth and yield of tomatoes and lettuce than the nutrient film technique.

5.2 RECOMMENDATIONS

Based on the findings in the present study the following recommendations are made:

- To establish a system with good water quality, both media bed and nutrient film technique systems are effective.
- To culture fish in an aquaponics system with good survival, condition factors, and growth performance both the media bed and nutrient film technique systems are equally recommended.
- To produce plants like tomatoes, which have high nutrient requirements, using a media-filled bed system of aquaponics is better, and using the nutrient film technique of aquaponics systems for tomato production is not recommendable.
- To produce lettuce, media bed is more favorable than nutrient film technique in aquaponics.

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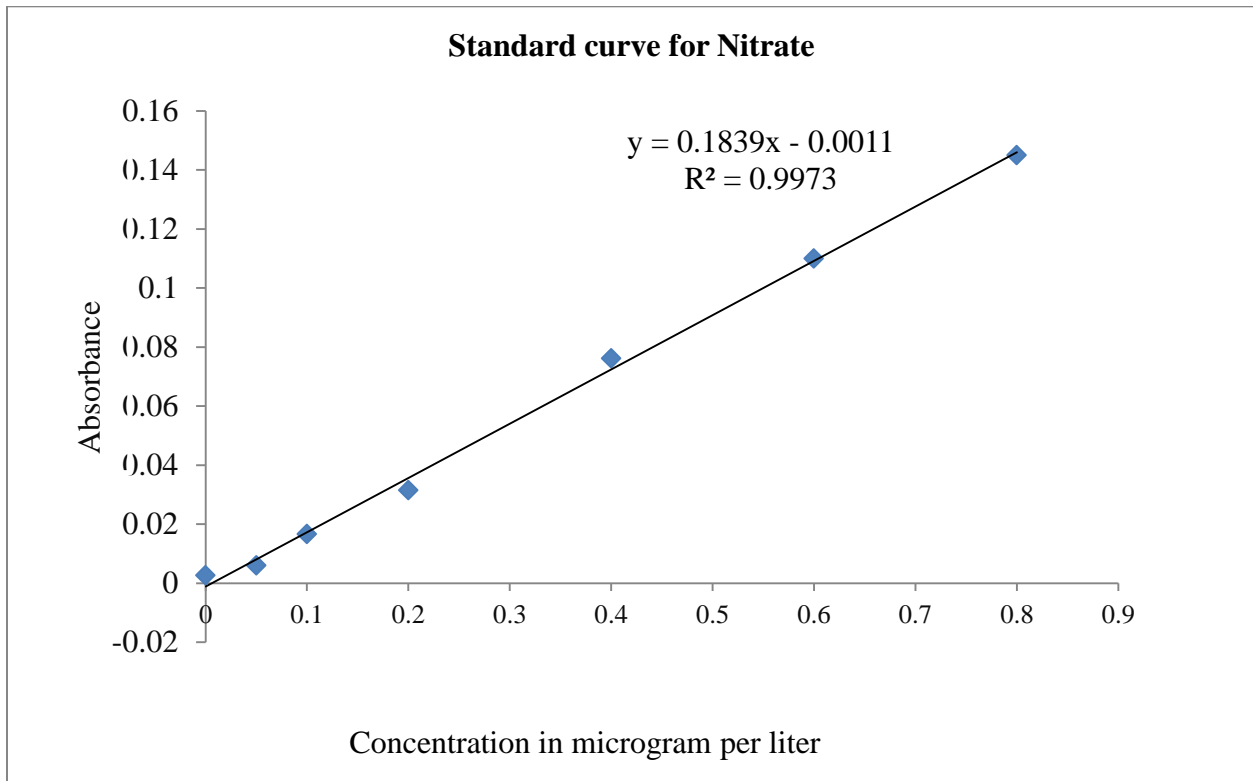
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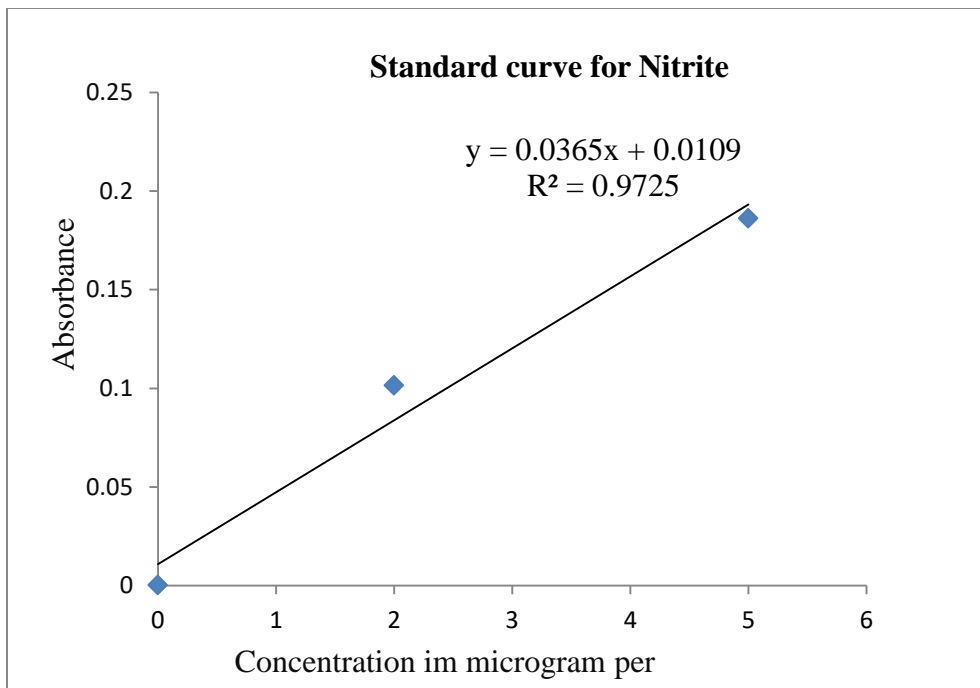
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APPENDIX

Standard calibration curve for Nitrate



Standard calibration curve for Nitrite





Preparation of NFT and media bed systems



Preparation of the seed bed and sowing of tomatoes and lettuce on the seed bed



Watering of lettuce and tomatoes



Planting of tomatoes and lettuce on the media bed and NFT



Tomato of NFT



Tomato of MB



Lettuce of bed



Lettuce of NF

Data collection of tomatoes and lettuce during the experimental period



Data collection of fish

