EVALUATING THE GROWTH PERFORMANCE OF THE AFRICAN CATFISH (*C. GARIEPINUS* BURCHELL 1822) AND OKRA (*ABELMOSCHUS ESCULENTUS* L.) IN AN INDOOR NFT AQUAPONICS SYSTEM.

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A DISSERTATION SUMBITED TO THE DEPARTMENT OF AQUACULTURE AND FISHERIES MANAGEMENT, SCHOOL OF NATURAL RESOURCES MANAGEMENT, NJALA UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BISCHOLOR OF SCIENCE HONOR DEGREE

OCTOBER 2024

ABSTRACT

Aquaponics is an integration of aquaculture and hydroponic technologies. The study evaluated the growth performance of the African catfish *Clarias gariepinus (*Burchell) and okra (*Abelmoschus esculentus*) in an indoor NFT aquaponics system. A recirculation aquaponic system (RAS) was adopted for a twenty-week (20-week) study period using a completely randomized design (CRD) that contained three tree treatments with five replicates. Fifty-two (52) fish was stocked at initial body weight of (21.84±15.33g) per single fish and okra seedlings were transplanted the third month within the study period. Catfish was fed twice a day at the rate of 5% for the first three months and 3% of body weight for the remaining months. Fish and plants were sampled biweekly during the whole study period. At the termination of the study, the highest monthly weight gained by a single catfish in July was (93.9±23.0) with 78.5% survival and FCR of (0.705±0.0). Data were analyzed using analysis of variance (ANOVA). The results revealed that treatment T1 had the highest yield (6.93±1.94) followed by T2 and T3 respectively in terms of number of leaves, plant height, leaf area and stem girth. The water quality parameters remained within suitable ranges for catfish production as well as the growth of okra. Overall, incentive performance in catfish growth and the okra production were satisfactory. Research in an open environment or greenhouse with 10-12 hours of light for increased crop yield, 3-4 months fish stocking before crop planting, avoiding overfeeding to prevent water pollution, and avoiding cannibalism to improve growth. The experiment demonstrates that nutrient film techniques (NFT) are effective for fish and okra growth in aquaponics systems, reducing malnutrition and food insecurity, and promoting sustainable land and water resource use in urban and peri-urban areas.

Keywords: Aquaponics, Catfish, Okra, Water Quality Parameters, Growth Performance

ACKNOWLEDGEMENT

I express my deep thanks and appreciation to the almighty God for his defined grace that made this of work a working art of success.

I am endlessly grateful to my father Dr. Johnson Jlopkeh Geply for laying my academic foundation and to my beloved mother Mrs. Esther Tuwor Gipply and my grandmother Richeal Tanwin for just everything. I also acknowledge my step-father Rev. Joshua N. Gipply for his moral and financial support. I also appreciate my brothers Jomie Jlopkeh Geply and Joshua N. Gipply Jr for their support.

I am most grateful to my supervisor Prof. Olufemi Julius Olapade for his encouragement, patience, tolerance and mentorship in guiding me through this project.

I am also grateful to the Integrated and Circular Technologies for Sustainable City Region Food System in Africa (INCiTis-EU-FOOD) system program for giving me the opportunity to conduct my project at its Living Laboratory.

I am beholden to all lecturers of the department of Aquaculture and Fisheries Management and lecturers of the school of Natural Resources Management, Mrs. Kadiatu Tucker, Cythia Howe,

DEDICATION

I dedicate this priceless book to my dear mother, Mrs. Esther Tolee Gipply. I adore you, and you are the most special person I have ever met. You are also my inspiration, my pillar of support, my flesh and blood, and most importantly, the reason I have to succeed. And to my father, who pushes me to achieve and realize my full potential, I love you.

CERTIFICATION

I certified that Mr. Abayonmin Woplu Geply in the department of Aquaculture and Fisheries Management, School of Natural Resources Management Njala University, Njala campus carried out this research work under my supervision.

Sign ______________________________ Date ____________________

SUPERVISOR

Prof. Olufemi Julius Olapade

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INTRODUCTION

1.1 Background

The need to adopt efficient production systems has paved the way for the development of urban farming methods such as Recirculatory aquaculture systems (RAS) and aquaponics systems with the world population growing rapidly. The regular aquaculture and farming systems cannot hold up to this speeding population growth. However, new method that combines both plant and fish aquaponics has been an emerging technology that would promote sustainable use of natural resources such as land and water (Boyd et al., 2020). This system is also environmentally friendly because it encourages green climate and organic food availability. *Clarias gariepinus* (Bruchell) is an ideal candidate to culture in aquaponics as it favors high density and poor water quality. According to (Costa-Pierce, 2022), fish stock has collapsed due to over-fishing and necessary components for a salubrious diet are scarce as a result of the increasing population. Research has revealed that the North African subspecies of the African catfish is very adaptive to extreme environmental conditions and can live in waters with the pH range of 6.5-8.0. The North African Catfish can live in very turbid waters and can tolerate temperatures of 8-35 degrees Celsius, as its optimal temperature for growth is 28-30 degrees Celsius (Teugels, 1986). They are bottom dwellers and do most of their feeding there, meaning the species can live in very poorly oxygenated waters which makes it one of the last species to live in such an uninhabitable place (Pienaar, 1968). It can attain sizes of up to 1.7 meters including the tail and can weigh up to 59 kg when fully grown. North African catfish lay their eggs in vegetation – hatching them within 25-40 hours. The larvae which are able to swim and feed within 2 or 3 days, as observed by Skelton (1993) grow very rapidly, with males reaching an ultimately larger size than females. They are known to feed on insects, plankton, snails, crabs, shrimps and other invertebrates.

Okra, *Abelmoschus esculentus* L. is a tropical season crop belonging to the family Malvaceae whose origin is traced to Ethiopia (Lamont, 1999). However, various okra varieties have since spread in the tropical regions of the world based on agro-ecological suitability (drought, temperature, Insect pests and diseases). Varieties of okra include Cajun delight, Clemson spineless and Spike, Burgundy okra, Jambalaya, Cow horn, Heritage okra, and Stubby. Clemson spineless (Abelmoschus esculentus) is an amazing food item famous for its nutritional, culinary, medicinal values and ability to grow in aquaponics due to its adaptability to expansive range of climatic conditions. The Plants grow to around 4 feet (1.2 m.) tall and the pods are mature in about 50 to 60 days. Clemson seeds are fairly inexpensive and the plants self-pollinate.

Fish is one of the utmost-traded food stuffs worldwide. The dietary contribution of fish is more momentous regarding animal proteins. Fish and vegetables are also necessary components of a salubrious diet. Their adequate daily consumption could help avert serious non-communicable maladies (Lock et al., 2005). Aquaponics is an integrated fish and plant production technology, essentially comprising two sub-systems, viz., ‘Aquaculture’ and ‘Hydroponics’. The underlying principle is to efficiently utilize water to produce two crops rather than one - and to partition and share nutrient resources between fish and plants. This farming system is commonly used in resource limited, urban and peri-urban areas to raise both fish and vegetable. It is basically a Recirculation Culture System, wherein fish are fed with quality floating pellet feed and waste water generated from fish is pumped into bio-filter troughs having horticulture plants and the flow rate of water adjusted with the help of the timer. The fishes and plants grown in aquaponics system ~~is~~ are totally organic - even though the initial investment of the system is high - the recurring cost is less and gives reasonable returns. The sustainable aquaponic environment has beneficial microorganisms living inside the system which has a positive influence on plant growth and thus purifies the water and in turn is reused for fish production (Wongkiew *et al*., 2017; Delaide *et al*., 2017). The fish excreta provide nutrients for the plants while the plants clean the water, creating a suitable environment for the fish to grow. Azad *et al*. (2016) reported that aquaponics is a viable food growing technology which connects consecutive aquaculture with hydroponics in a symbiotic condition.

1.2 Aim and objectives of the study

This study aims to evaluate the growth performance of the African catfish (*C. gariepinus)* and okra (*Abelmoschus esculentus L.)* in an indoor facility with the view of determining the best growth medium for production of the fish in such a situation.

1.2.1 Specific objectives are to:

1. Investigate the growth performance and nutrient utilization of the African catfish in an indoor NFT aquaponics system,
2. Assess the growth parameters and yield of okra in an indoor NFT aquaponics system, and
3. Evaluate the water quality for okra and catfish in an indoor NFT aquaponics system.

1.3 Justification of study

Basically, agricultural as well as fisheries activities requires land. However, continuous global population growth and extreme weather conditions caused undoubtedly by the current climate crisis make access to farmlands very competitive. This makes Agri-aquaculture system one of the options in fish farming in many countries including African countries, as aquaculture is encouraged to compensate for land scarcity in fish production to meet the demand of fish protein for the growing population. Therefore, the outcome of the investigation would enhance the practice of this system fish of farming in the study area and beyond.

One of the components of the nutrient film aquaponics system is a plant or a crop. A fish species is bred in an enclosure in which a plant or crop is also cultivated to create an interdependent or symbiotic relationship such that the fish excreta provide nutrients for the plant while the fish feed on the plant. Simply, this Agri-aquacultural system encourages the share of scarce resources between aquaculture and crop production such as water and nutrients to achieve farmers' economic objectives in an environmentally friendly situation. Okra (*Abelmoschus esculentus L)* is the plant used in the research. Assessment of the growth parameters and yield of the crop is important for promotion of aquaculture in Moyamba District, Sierra Leone and the rest of the Mano River Union countries.

Obviously, water is an essential part of renewable natural resources including agriculture and aquaculture – not just any water but water of suitable quality. The same quality of water required by a certain plant species to flourish may be different from that of a fish species. However, in nature it is common to see plants and fish species occurring in the same aquatic environment, which is a clear indication of the interdependence between fish species and plants. Hence, evaluating the quality of the water in which the okra and catfish are bred in door the NFT aquaponics system is necessary because the result would increase knowledge and skills on catfish production using the system in study area particularly, and generally in the Mano River Union belt and Africa.

1.4. Statement of problem

As the world's population grows so is the demand for food production expand, which makes the competition for resources such as land, water and nutrients much higher nowadays. These realities call for alternative sustainable and reliable methods to provide much needed foodstuffs including fish products. Clearly one of the innovative approaches is the indoor NFT aquaponics system. However, there has been inadequate knowledge on the NFT aquaponics system to fish farmers in Moyamba District and its environs. This study therefore would seek to contribute to the availability of such technical knowledge.

The nutrient film techniques being a system, requires the incorporation of other resources such as plants to make it effective. There are many plants though, but the system favors plant species especially annuals that is fast-growing with bumper harvest. Okra apparently has stood out as one of the choice plants for the NTF aquaponics system. Nonetheless, there is insufficient information on the suitability of okra for this type of indoor breeding of catfish in terms of growth performance as well as yield production. This research would attempt to provide such necessary information in the study area.

Water is another essential resource for the NTF aquaponics system. Traditionally catfish is cultured in tanks and ponds, a practice which may result in water pollution due to poor waste disposal. NTF aquaponics system is a promising alternative; however, there is inadequate knowledge on the suitable water quality for this indoor facility for catfish production. Hence at the end of this investigation, solution would be proffered to bridge the gap in such technical knowledge in Moyamba District and beyond.

CHAPTER TWO

2.0 Literature Review

2.1 Introduction

The emerging of new food production techniques Aquaponics is a technology that is a subset of a broader agricultural approach known as integrated Agri-aquaculture systems (IAAS) (Gooley and Gavine 2003). This discipline consists of integrating aquaculture practices of various forms and styles (mostly fish farming) with plant-based agricultural production. The rationale of integrated Agri-aquaculture systems is to take advantage of the resources shared between aquaculture and plant production, such as water and nutrients, to develop and achieve economically viable and environmentally more sustainable primary production practices (Gooley and Gavine 2003). The objective of this study is to alleviate the demand for our natural resources to save our planet. The conventional method or farming system is unable to meet the demand for urban residents, a situation that, if left unaddressed, could pose problems for future generations. Global warming is on the verge of limiting human food production and increasing our wellbeing. Urban and peri-urban communities must find alternatives for food provision, which this study seeks to address or provide (Sandin et al., 2023).

2.2 Biology of African catfish

Clarias gariepinus is considered to be omnivorous, displaying both scavenging and predatory behavior (Bruton 1979a). It also has an extremely varied diet, consuming fruits and seeds, all types of aquatic invertebrates and small vertebrates, small mammals, and even plankton (Skelton 2001).

Larger individuals show a specific dietary shift towards fish as they grow bigger (Willoughby & Tweddle 1978). However, inactive foods, which it detects with its sensory barbells before securing with its array of very fine teeth prior to gulping, are generally preferred. Adults occur mainly in quiet waters, lakes, and pools (Teugels 1986) and prefer rather shallow and swampy areas with a soft, muddy substrate and calmer water (Seegers 2008). They may also occur in fast-flowing rivers and in rapids. The presence of an accessory breathing organ enables this species to breathe air when very active or under very dry conditions. They remain in the muddy substrates of ponds and occasionally gulp air through the mouth (de Moor and Brunton 1988). Migrate to rivers and temporary streams to spawn. During intra-specific aggressive interactions, this species was noted to generate electric organ discharges that were monophasic, head-positive, and lasting from 5-260 ms (Baron et al. 1994). Oviparous, Spawning takes place during the rainy season in flooded deltas. The fish make a lateral migration towards the inundated plains to breed and return to the river or lake soon afterwards, while the juveniles remain in the inundated area. Juveniles return to the lake or river when they are between 1.5 and 2.5 cm long (Witte and de Winter 1995). First sexual maturity occurs when females are between 40-45 cm and males between 35-40 cm. Eggs are greenish. Incubations last little (about 33 hours at 25 °C). Under certain conditions, they ripe all year round, and under ideal conditions, a ripe female may lay about 60 000 eggs.

2.2.1 Nutritional requirement of African catfish

Aquaculture production and its contribution to global food fish have continued to increase significantly, reaching 122.6 million tons, of which 87.5 million tons were aquatic animals and 35.1 million tons of algae (FAO, 2022). Its propensity toward a carnivorous feeding habit suggests that *C. gariepinus* has a relatively high dietary protein requirement, in the order of 40–50 percent of crude protein on a dry weight basis. The fact that the animal also feeds on plant material reflects its ability to digest plant proteins and utilize carbohydrates as an energy source. Balance of dietary energy is critical for determining feeding standards for fish. Energy is released by the metabolism of lipids, carbohydrates, and amino acids (proteins) (Robinson & Li, 2015). In fish feeds, the main source of energy is the carbohydrates and lipids. The African catfish requires a low-carbohydrate diet, with recommended carbohydrate content between 26 and 32%. Proteins are large organic, nitrogen-containing compounds formed by linkages of individual amino acids (Alberts et al., 2002). Protein requirement information is one of the most important aspects of fish nutrition because proteins, which are synthesized from amino acids, are essential for fish growth, tissue repair (Keremah & Beregha, 2014; Miles & Chapman, 2006), and if in excess for energy (Craig & Helfrich, 2017). Protein comprises about 70 percent of the dry weight of fish muscle. A continual supply of protein is needed throughout life for maintenance and growth. Lipids (fats and oils) are an easily digested source of concentrated energy, having more than twice as much energy as an equal amount of carbohydrates. Catfish apparently require 0.5 percent to 0.75 percent omega-3 fatty acids in the diet. Catfish feeds are generally supplemented with vitamin premix that contains enough of all essential vitamins to meet the requirement and make up for losses from feed processing and storage. The nutrients required for the growth performance of African catfish are carbohydrate, protein, amino acid, lipid, mineral, and vitamin. Feeds used in aquaculture are designed to satisfy the dietary requirements of fish species while ensuring the ratio of protein, carbs, and fats (Geay & Kestemont, 2015).

2.2.2 Economic importance of African catfish

Fish farming is the sub-set of aquacultures that focuses on rearing of fish under controlled or semi-controlled conditions for economic and social benefits (Anthonio and Akinwumi, 2002). Food and Agriculture Organization (2002) made a statement that fisheries products represented a major source of export revenue for developing countries, amounting to over US $ 20 billion per annum in the late 1990s. This exceeded the values obtained from the exports of meat, dairy, cereals, vegetables, fruit, sugar, coffee, tobacco, and oilseeds in 1997 from developing countries (International Trade Centre, 2002). It serves as a source of income, reduces the rate of unemployment in the economy, and increases the Gross Domestic Product (GDP). For many developing countries, catfish is one of Africa's most commercially important freshwater fish. Its trade gives local producers significant employment and contributes to curbing food insecurity in the population (FAO 2006). Catfish growth has created many opportunities for jobs at different marketing levels, thereby improving participants' income and well-being. (Ugwumba and Chukwuji 2010).

2.2.3 Nutritional values of African catfish

According to Anoop et al. (2009), it provides food for the populace; it allows for improved protein nutrition because it has a high biological value in terms of high protein retention in the body, higher protein assimilation as compared to other protein sources, low cholesterol content, and is one of the safest sources of animal protein. This is so because of its low caloric value, low carbohydrate content, high in protein, low in fat, it is quick and easy to prepare, and above all, it tastes great. (Vanguard, 2009). The protein needed for growth, particularly in children, was inadequate because the animal protein was expensive. Protein from fish sources within reach is the only cheaper source of protein to bridge the gap of protein deficiency. The process of handling and marketing catfish is very delicate if quality and nutritional value are to be maintained due to its short shelf life and also reduce the nutrient content of the fish.

2.3 Biology of okra

Okra is included in the genus Hibiscus, section *Abelmoschus*, in the family Malvaceae (Linnaeus, 1753). The section *Abelmoschus* was subsequently proposed to be raised to the rank of distinct genus by Medikus, 1787. The wider use of Abelmoschus was subsequently accepted in the taxonomic and contemporary literature (Hochreutiner, 1924). This genus is distinguished from the genus Hibiscus by the characteristics of the calyx, spathulate, with five short teeth, connate to the corolla, and caducous after flowering (Kundu and Biswas, 1973; Terrell and Winters, 1974). Although about 50 species have been described, eight are most widely accepted (Singh et al., 2014). Okra is mainly propagated by seeds and has a duration of 90-100 days. It is generally an annual plant. Its stem is robust, erect, variable in branching, and varying from 0.5 to 4.0 meters in height. Leaves are alternate and usually palmately five lobed, whereas the flower is axillary and solitary. Okra plants are characterized by indeterminate growth. Flowering is continuous but highly dependent upon biotic and abiotic stress. The plant usually bears its first flower one to two months after sowing. The fruit is a capsule and grows quickly after flowering. The greatest increase in fruit length, height, and diameter occurs during the 4th to 6th day after pollination.

2.3.1 Nutritional requirements of okra

For okra production, fertilizer is an essential input. The supply of fertilizer is indispensable to improving the soil nutrient status and increasing crop yield. Olaniyi et al. (2010) reported that for better growth and development of okra, it requires nutrients such as nitrogen, phosphorus, potassium, calcium, sodium, and sulfur for fertility support and okra production. Lack of sufficient amounts of these nutrients leads to poor performance of okra, with growth affected, yielding a low amount of produce (Olaniyi et al., 2010). The use of organic manure for okra production has helped to improve agricultural practices in some parts of the African continent. Nitrogen is considered an essential element of biomolecules such as amino acids, proteins, nucleic acids, phytohormones, and a number of enzymes and coenzymes (Don 2010) that stimulate growth, expansion of the crop canopy, and interception of solar radiation (Milford et al., 2000). It plays an important role in chlorophyll, protein, nucleic acid, and hormone and vitamin synthesis and also helps in cell division and elongation. Phosphorus stimulates root development, increases stem strength, improves flower formation and seed production, leads to more uniform and earlier crop maturity, improvements in crop quality, and increased resistance to plant diseases. Phosphorus helps in nutrients uptake by promoting root growth and thereby ensuring a good pod yield through the increase in total dry matter, Rao (1995), and P deficiency results in poor root development and poor pod setting and subsequently reduces yield (Jam et al., 1990; Mohanta 1998; Sadat 2000). Similarly, potassium is one of sixteen essential nutrient elements required for plant growth and reproduction.

2.3.2 Economic importance of okra

With vegetables being part of man's daily ingredients no matter the location and position, the cost of production must require less labor, and economic value must be of high interest, especially okra. With increased demand and low productivity, farmers use large-scale production. High levels of productivity are not obtained due to the inefficient use of available agricultural resources and difficulty in obtaining economic resources (FAO 2017; World Bank 2015). In retail markets, okra is expensive yet popular, particularly in the southern United States, Africa, Asia, and the Caribbean (Calisir et al., 2005; Adelakun et al., 2009; Sengkhamparn et al., 2009). Thus, okra has a high value, with average retail market prices ranging from $3.45/kg in the frozen form to $7.07/kg when sold fresh (USDA ERS, 2016). It can also be pickled or canned. It is relatively easy to grow and has high yields (Franklin et al., 2015). With the short duration of production and being very cost-efficient, plus its high demand and low annual production, okra production creates jobs for the locals' farmers to generate income.

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2.3.3 Nutritional value of okra

Okra (*Abelmoschus esculentus*) is an annual shrub-bearing plant native to the African continent, whose fruits are rich in carbohydrates, proteins, vitamins, minerals, and unsaturated fats (Filgueira, 2012). Okra is a good source of carbohydrate, dietary fiber, fat, protein, calcium, iron, thiamine, riboflavin, nicotinamide, and ascorbic acid (Ewa et al., 2011). Clemson spineless provides many nutritional benefits to consumers, especially children that are malnourished. The protein found in okra is very important in the human diet; it helps to build muscle tissue and make up enzymes that control all the hormones that control the organs. Okra is mainly cultivated for its "pods," which are cooked and eaten in African countries like Nigeria, Egypt, and Sudan. It is also important in other tropical areas, including Asia and South America; fresh okra fruits are used as vegetables, while the roots and stems are used for preparing brown sugar.

2.4 Food security in Africa

Africa faces a number of critical challenges. According to Klaus Topfer (UNEP 2002: XV), the environment continues to deteriorate; social and economic inequality is increasing; and globalization is sweeping across the world, largely leaving Africa behind. A clear outcome of these harmful processes is a significant decline in agricultural production, poverty, and food insecurity. Agriculture, of which 85-90 percent is rain-fed in sub-Saharan Africa, accounts for 35 percent of the region's gross national product (GNP), 40 percent of exports, and 70 percent of employment (World Bank, 2000). Fish is a basic food in sub-Saharan Africa. It plays a key role as a supplier of a concentrated form of food energy and protein of high biological value that is often complementary to the limiting amino acids in the plant foods eaten so heavily in the diet of people in the developing countries. For the majority of the human population, fish has a lower income elasticity of demand than meat, with vegetables and beans as substitutes for fish (Delgado & McKenna 1997). Though it provides an estimated 22% of the protein intake in the region, per capita supply/availability is the lowest in the world (Dugan 2003). The beginning of the 1990s saw a decline in per capita food levels in 80 percent of all Sub-Saharan African (SSA) countries. Despite the high population growth rate, the trend in Africa's food output compared with the rest of the world reflects significant differences in output performance as well as population growth rates. The common short-run definition of food security in a single country or in the world at large is the ability of food-deficit countries, regions within countries, or households within these countries to meet target consumption levels on a year-to-year basis (for example, Valdes 1981:2 and Bigman 1985:6, among others). Global food security is rapidly increasing. In 2021, an estimated 29.3 percent of the global population (2.3 billion people) was moderately or severely food insecure, while 828 million people in the world (10.5 percent of the world population) faced hunger (FOA 2022). Today, 1 billion people are still suffering from starvation, undernutrition, and malnutrition, and the Food and Agriculture Organization (FAO) has determined that we are still far from achieving the first Millennium Development Goals (MDG), which are related to eradicating poverty and hunger by 2015. There are 239 million hungry people in sub-Saharan Africa, and this number may rise in the near future (Sasson, 2012).

2.5 Theoretical Framework

Creativity in agribusiness is the key to meeting food problems. Hence the limited space and resources in urban farming cultivation, for now, is a big deal, and deal with a food product of fish and vegetables (Love et al., 2015; Pollard et al., 2017). Agricultural innovation has played a major role in improving food security, reducing hunger and poverty, and improving rural livelihoods. Agricultural innovations such as improved seed varieties have enabled smallholder farmers to increase their yields and incomes. Innovation in agribusiness has created new employment opportunities and improved access to markets for farmers, leading to increased incomes and better livelihoods (Pingali 2012). But agricultural growth has been accompanied by negative effects on climate, natural environment, public health and nutrition, and social justice (Barret et al. 2020a; Pingali 2012). Another major focus for innovation should be the development of scaled-up farming systems that boost farm level efficiency, production, and income and, as a result, also become more environmentally friendly and climate-smart.

2.5.1 Evolution of food system

The post-Second World War context created an institutional environment that placed the state at the center of productive investments in order to quickly rebuild the foundations of global food production. Technical changes brought about a slow agricultural revolution, differentiated according to regions and sectors, closely linked to the growth of industry and trade (Vanderpotten, 2001). A major technical change in European agriculture was the abandonment of fallowing, replaced by the cultivation of forage and legume crops5 (Griffon, 2017), thus reducing the need for arable land to meet food needs. The changes also concerned many other aspects: tools (ploughs, scythes, etc.), application of lime and fertilizer, drainage and irrigation, selective breeding of livestock, new crops and rotations, mechanization and motorization (threshing machines, traction engines, followed by tractors). These changes were mainly driven by developments exogenous to agriculture, such as the modification of the conditions of access to the commons (land), the growing demand for food in cities as well as in the countryside, the mobilization of fossil energy (coal) and of the steel and chemical industries, the growth of land and sea transport, and the expansion of international trade (Losch, 2015).

2.5.2 Current trends and innovations

The introduction of aquaponics, hydroponics, and aeroponics has shifted global food production, reducing the demand and pressure on conventional farming systems. Urban and peri-urban dwellers have taken advantage of the innovation by utilizing their backyards (Swiader et al., 2023). To improve crop management, cutting-edge technologies like drones, Internet of Things sensors, and machine learning (McEnroe et al., 2022). These tools help farmers to make good decisions and use resources efficiently by keeping crop health, soil conditions, and weather patterns in real time. Sorting, packing, and quality control are among the tasks that robotics streamlines to increase productivity and cut labor expenses (Kumar et al., 2023). Sustainable practices are a major focus of food processing innovations. Energy-efficient equipment lowers the carbon footprint of production processes, while methods like high-pressure processing (HPP) increase shelf life without the need for preservatives. Agro-businesses are embracing omnichannel strategies that integrate online and offline sales channels. The new trend not only seeks food production but also sustainability of land and water resources.

2.5.3 Food production and technology.

Food production is not meeting the demand of the rapid population growth, and the conventional methods of farming have failed to be a remedy. Mechanical farming, however, could not keep up with environmental issues like global warming. However, new technologies like hydroponics, which is the cultivation of crops in a greenhouse that requires little space with electricity and can be done in the backyard, The most prominent that provides both fish and plants along crop, aquaponics is the cultivation of fish and plants together in a constructed, recirculating ecosystem utilizing natural bacterial cycles to convert fish waste to plant nutrition. This system has the advantage of using less water, a lesser area of land, waste renewal, less labor, etc. Both promote peri-urban farming and are environmentally friendly. This is not limited to food production but also food preservation and food safety (Rau, 2021).

2.5.4 Innovation in food production

Over a billion people in the world are currently undernourished. (World Food Programme, 2014). Christopher et al. (2014) reported that current estimates are that 38% of global agricultural land is degraded; this normally results in reduced yields due to a lack of or insufficient nutrients (The World Bank, 2015). Innovation means change. In the case of food and agriculture, it can be the application of new proposals for raw material processing technology, packaging of products, new food additives, and new agricultural technologies. Aquaponics is especially valuable in areas where land and water aren't plentiful. Aquaponics is often hailed as the future of food production. Aquaponic systems are said to utilize only 2 to 10% of the water required in traditional vegetable or crop production and have the potential to produce 10 times the output without the use of harmful chemicals or pesticides (Christopher et al., 2014). The underlined purpose of this technology allows the fish, plants, and bacteria to thrive symbiotically and to work together to create a healthy growing environment for each other, provided that the system is properly balanced.

2.6 Aquaponics

Aquaponics is the cultivation of fish and plants together in a constructed, recirculating ecosystem utilizing natural bacterial cycles to convert fish waste to plant nutrition. This system has the advantage of using less water, a lesser area of land, waste renewal, less labor, etc. Plants and animals in an aquaponic system have a mutualistic relationship with each other. The fish excreta provide nutrients for the plants, while the plants clean the water, creating a suitable environment for the fish to grow. Aquaponics is beneficial for everyone who wants to grow food, and it can be done just about anywhere that has access to clean water and energy. In addition, aquaponic systems require less water quality monitoring than separate hydroponic or recirculating aquaculture systems and require less land and water than ponds and gardens (Rakocy 2006).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The study area

The study was carried out at Njala University Living Laboratory (NUSL-LL) which is part of the Integrated and Circular Technologies for Sustainable City Region Food system in Africa (INCiTis –FOOD) project at the Department of Aquaculture and Fisheries Management, School of Natural Resources Management, Njala University, Njala Campus, Moyamba District, Kori Chiefdom, Sierra Leone. The district is the largest in the Southern Province by geographical area, occupying a total area of 6,902 km^2 (2,665 sq. mi) and comprising fourteen chiefdoms (Manson *et al.,* 2009). According to Sierra Leone Census Commission (2021), Moyamba District has a population of 346,771. It borders the Atlantic Ocean in the west, Port Loko District and Tonkolili District to the north, Bo District to the east and Bonthe District to the south.

Figure. 3. 1: Njala University Living Lab Building

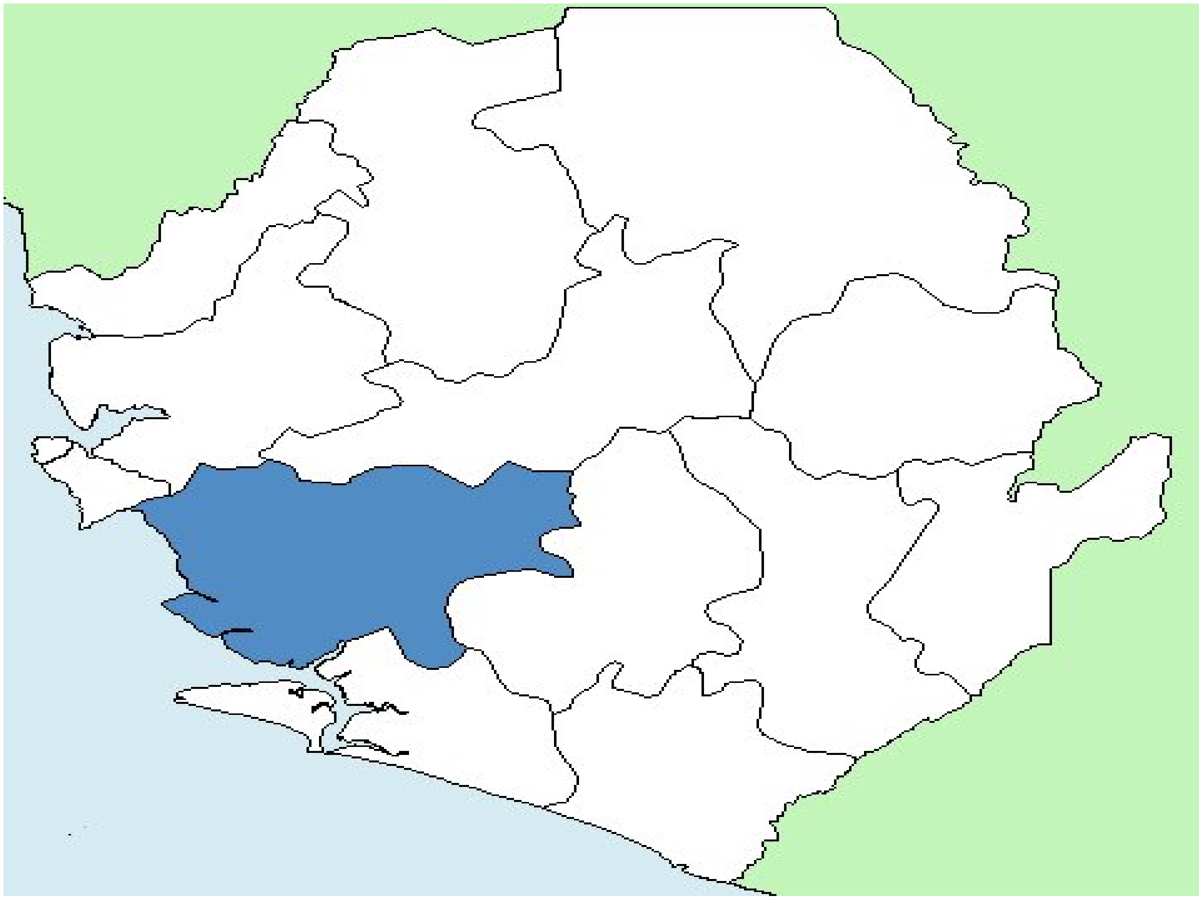

Figure 3.2 Moyamba District Map in Blue

3.1.1 The climate and vegetation of the study area

Moyamba District has two distinct seasons (rainy and dry seasons) like the rest of Sierra Leone. The rainy season begins in May and ends in October while the dry season is from November to April; there is low variation in the climate throughout the district with relative humid of (>0.65 p/pet). Located at an elevation of 61 meters (200.13 feet) above sea level, Moyamba has a tropical monsoon climate. The district's yearly temperature is 28.5ºC (83.3ºF) and it is 0.89% higher than the country's average temperature. Large portion of the natural vegetation remains intact; and the main vegetation types are grassland, mangrove, inland valley swamp and mostly secondary farm growth.

3.2 Experimental design

This study was conducted within 20 weeks (five months) in an indoor recirculating aquaponics system (RAS). The research is a randomized block design experiment. It consists of three (3) treatments and five (5) replicates per treatment with 5 plant stands in each replicate and 25 plant stands in each treatment making the total of 75 plant stands. The inter row spacing is 35 cm and intra-row 30 cm. The roof of the indoor aquaponics system was a blue translucent zinc.

3.2.1 Aquaponics system set up

The aquaponic system components consisted of the sump, water holding tank which measured 1.5 m in length and 90 cm width and held 1000 litters of water to supply the rearing tank using lift pump. The pump supplied water at a rate of 40 liters per minute into the rearing tank. The rearing tank was 35 cm from ground level and measured 75 cm in height, 1.16 m in length and 90 cm in width with a water holding capacity of 750 liters which supplied the radar tank. The radar tank supplied the bio-filter sludge tank through which waste water from the radar tank was released to mitigate sediments. The bio-filer contained fine sand to eliminate sediments that escaped the radar. It supplied the plants at a rate of 1.6 liter in PVC pipe. The sludge tank, radar and bio-filter were set on the ground. They measured 1m in height, 20 cm in length and width and held 250 liters of water each. The 4-inch PVC pipe measured 8ft. in. length. The bottles used were 12 cm in length with 4 cm going into the PVC pipe and 3 cm at surface level. Water flowed to the growth beds through a capillary force or compression. The growth beds contained growth media like bottles to hold substrate to anchor the okra. Sawdust weighing 1.3 kg and carbonized rice husk (400 g) were mixed as substrate to increase the filtration and aeration for the okra. The water that flowed through the growing beds dipped into the sump and the lift pump supplied water again to the rearing tank; this process is called the Recirculatory Aquaponics System (RAS). The irrigation system is 3 quarter pipes.

3.3 Sourcing of experimental fish

Juveniles of African catfish used in this study was sourced from TimRex Integrated Farm Mile 91, Moyamba District, Sierra Leone and were transported in mini trout with aerator to supply oxygen. Fifty-two (52) African catfish fingerlings were stocked on March 24, 2024 with an average initial body weight of 28g (single fish) and 1,447g (in total). Catfish was fed twice a day at the rate of 5% for the first three months and 3% of body weight for the remaining months. The fish feed of 2.0 mm contained crude protein 45%, crude fat 11%, crude fiber 2.0%, moisture 9.0%, ash 8.0% and phosphorus 1.3%. For 4.5 mm, crude protein 42%, crude fat 11%, crude fiber 2.0%, moisture 9.0%, ash 10% and phosphorus 1.2%.

To maintain the water level and replace water lost due to evaporation, aerated clean water was periodically added to the fish tank. All the 52 Fish was taken from the tank every biweekly to measure the weight in order to determine the amount of fish feed and fish growth rate for the next two weeks using the electronic scale (Model: EK3250). The weight of fish feed given is calculated according to the change in fish weight. Hence, biological evaluation carried out to determine fish growth include: Weight Gain [g], Food Conversion Ratio (FCR), Specific Growth Rate [g] and Survival Rate [%], Protein Efficiency Ratio (PER), Protein Intake (PI) and Feed Intake (FI).

WG (g) = final body weight (g) – initial body weight (g)

$$SGR = \frac{\text{In (Final body weight, g) – In (Initial body weight, g) X 100}}{\text{Days}}$$

FCR – Food Conversion ratio= Feed given ÷ Fish weight gain

$$SR (\%) = \frac{\text{fish stocked - mortality}}{\text{Fish stocked}} \text{ X } 100$$

Feed Intake= Initial body weight, g X Feeding rate (5%) X Time (Days)

PI - Protein Intake= Total feed intake X Protein percentage of feed (Raanaa feed, 45%)

$$\text{PER - Protein Efficiency Ratio} = \frac{\text{Final body weight, g – Initial body weight, g}}{\text{Amount of protein fed}}$$

3.4 Cultivation of okra

Well hygienic and disease-free (African green F1-HYBIRD) okra seeds were bought in Ghana from JAVA seed and first planted on nursery beds. The seedlings were transplanted 6 days later into growing beds in the aquaponics system. The Okra seedlings were transplanted 3 months after stocking catfish. The plants at the edge and middle of each replicate were measured for plant height, number of leaves, leaf length and width, and stem girth using a measurement tape and caliper calibrated in centimeters. The stem girth was measured just below the first node from substrate. The Okra leaves area was calculated using the following equation:

$$\text{Leave area (cm2)} = c \times L \times W$$

3.5 Water quality analysis

Samples of water were taken from the culturing tank biweekly for chemical analyses. The parameters such as pH, temperature ^{O}C, electrical conductivity, total dissolved solid (TDS), total ammonia nitrogen (TAN), nitrite nitrogen (NO2--N), nitrate nitrogen (NO3--N), total phosphorus (P), alkalinity (Ak), salt and dissolved oxygen (DO) were analyzed using water quality parameters reagents and multi-parameter kits. Continuous monitoring of these parameters is imperative to maintain optimal water conditions in the culturing tank for the successful growth of catfish and vegetable.

3.6 Data Analysis

Data were collected biweekly and subjected to a One-way analysis of variance (ANOVA) and means for monthly analysis at 5% level of significant differences ($P<0.05$) using Duncan's multiple range test (IBM SPSS 27.0.1). This was done for catfish and water quality parameters while okra data were analyzed on a biweekly basis.

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

Table 4. 1: Growth performance and nutrient utilization of *Clarias gariepinus* in an indoor Nutrient Film Technique (NFT) aquaponics system

Parameters	March	April	May	June	July
Weight gain [g]	$21.84{\pm}15.33^{ab}$	$32.06{\pm}10.17^{b}$	77.64±19.93bc	$93.9{\pm}23.0^{c}$	$74.29{\pm}41.48^{a}$
Specific growth rate	$10.98{\pm}15.53^{ab}$	$24.58{\pm}2.305^{b}$	$30.96{\pm}1.85^{ab}$	$32.33{\pm}1.76^{ab}$	$30.16{\pm}4.21^{a}$
FCR	$0.705{\pm}.0^{a}$	$.70{\pm}0.0^{a}$	0.69±0.0a	$0.7{\pm}0.0^{a}$	$0.705{\pm}0.0^{a}$
PI	$12.18{\pm}4.82^{ab}$	$31.88{\pm}5.54^{b}$	$70.26{\pm}20.43^{bc}$	$126.5{\pm}24.53^{c}$	$79.01{\pm}111.71^{a}$
PER	$1.23{\pm}1.74^{a}$	$1.703{\pm}1.15^{a}$	$1.70{\pm}0.09^{a}$	$0.96{\pm}0.65^{a}$	$0.48{\pm}0.24^{a}$
Feed intake	$27.06{\pm}10.73^{b}$	$70.84{\pm}12.31^{c}$	$150.14{\pm}45.41^{d}$	$281.16{\pm}54.53^{d}$	$175.5{\pm}284.3^{a}$
Survival rate (%)	$99.0{\pm}1.41^{c}$	$92.0{\pm}0.0^{d}$	$90.0{\pm}0.0^{c}$	$85.0{\pm}0.0^{bc}$	$78.5{\pm}4.94^{a}$

Values with the same letter subscript are not significantly different $P<0.05$. (DMRT)

All things considered, the data clearly show a pattern of growth performance peaking in June with variations in feed intake, weight gain, and SGR according to environmental and management parameters (Table 1). Fish effectively turn feed into weight during optimal times, as indicated by the stability of FCR despite dropping PER and survival rates.

Table 4. 2: Morphological growth parameters and yield of Okra in an indoor aquaponics system

Treatment	WK 2	WK 4	WK 6	WK 8
No. of Leaves				
Plot 1	3.27±0.45^{a}	6.67±1.04^{c}	8.80±1.20^{a}	10.0±2.92^{b}
Plot 2	3.33±0.48^{a}	6.0±0.75^{b}	7.78±1.12^{a}	9.27±6.80^{b}
Plot 3	3.47±0.48^{a}	5.33±0.48^{a}	8.60±1.30^{a}	6.80±2.14^{a}
Plant Height				
Plot 1	9.46±2.02^{b}	15.0±3.31^{a}	17.19±4.23^{a}	34.72±12.72^{b}
Plot 2	9.06±1.69^{b}	16.47±3.18^{a}	24.32±3.81^{c}	26.93±6.74^{a}
Plot 3	7.73±1.39^{a}	15.47±3.09^{a}	20.23±3.31^{b}	26.13±5.76^{a}
Leaf Area				
Plot 1	2.77±0.34^{a}	7.92±2.07^{c}	10.14±2.59^{b}	14.04±4.60^{b}
Plot 2	2.62±0.23^{a}	6.57±1.87^{b}	7.62±2.05^{a}	12.41±3.04^{ab}
Plot 3	2.68±0.30^{a}	4.80±0.90^{a}	7.45±2.99^{a}	10.63±3.75^{a}
Plant Girth				
Plot 1	0.10±0.0^{a}	0.26±0.07^{b}	1.18±0.49^{b}	1.44±0.58^{b}
Plot 2	0.10±0.0^{a}	0.16±0.06^{a}	0.63±0.19^{a}	0.76±0.29^{a}
Plot 3	0.10±0.0^{a}	0.47±0.05^{a}	0.60±0.16a	0.74±0.19^{a}
Okra Yield				
Treatments	Treatment 1	Treatment 2	Treatment 3	
Values	6.93±1.94^{b}	6.0±1.69^{b}	4.33±1.54^{a}	

Values that have the same letter(s) superscript in column are not significantly different using DMRT ($P<0.05$); ns: not significant.

The total number of leaves increased from 2-8 weeks after planting (Table 2). There was no significant difference ($P<0.05$) in the number of leaves at the early stage (2WAP). However, significant differences ($P<0.05$) were observed among the number of leaves at later stage (4-8WAP). There were significant differences ($P<0.05$) at (WK4) for all treatments but no significant difference (p>005) between 2.5 and 8WK). The total leaf area increased from 2-8 WAP. This result indicates no significant ($P<0.05$) difference in (2WAP) in all treatments while major ($P>0.05$) difference occurred in (4-8WAP) with T1 (14.04±4.60^{b}) (8WAP). There was no significant ($P<0.05$) difference for WK2 while stem girth had significant difference ($p>0.05$) at middle and later stage. The result obtained showed T1 (6.93±1.94^{b}) out-performed T2 (6.0±1.69^{b}) and T3 (4.33±1.54^{a}) in terms of okra yield.

Table 4. 3: Monthly water quality parameters requirements of *Carias gariepinus* and okra

Parameters	March	April	May	June	July
DO ppm	6.35±1.202^{a}	6.35±1.202^{a}	8.55±0.212^{a}	8.05±1.909^{a}	7.15±3.606^{a}
Temp ^{O}C	29±2.404^{ab}	29.8±4.949^{a}	26.75±0.494^{a}	28.2±2.262^{a}	31.8±7.071^{ab}
pH	7.1±0.424^{a}	6.95±1.060^{a}	7.3±0.141^{a}	7.3±0.565^{a}	6.85±1.060^{a}
Ammonia ppm	0.04±0^{a}	0.045±0.007^{a}	0.025±0.007^{a}	0.035±0.007^{a}	0.04±0.014^{a}
Nitrate ppm	0.035±0.007^{a}	0.03±0.014^{a}	0.03±0.014^{a}	0.03±0.014^{a}	0.035±0.021^{a}
Nitrite ppm	0.015±0.007^{a}	0.015±0.007^{a}	0.015±0.007^{a}	0.015±0.007^{a}	0.025±0.007^{a}
Cond: µS/cm	731.5±81.31^{c}	1054±91.92^{c}	1169±59.39^{c}	1309.5±16.263^{c}	1404±33.94^{d}
TDS mg/l	77±36.76^{b}	136.5±24.74^{b}	231.5±43.13^{b}	317±42.42^{b}	403.5±24.74^{c}
Phosphate mg/l	0.06±0.056^{a}	0.015±0.007^{a}	0.01±0^{a}	0.015±0.007^{a}	0.015±0.007^{a}
Salt ppt	0.25±0.014^{a}	0.24±0.424^{a}	0.24±0.014^{a}	0.265±0.007^{a}	0.21±0.014^{a}
Alkalinity mg/l	23±1.414^{ab}	23±2.828^{a}	25.5±2.121^{a}	30±5.656^{a}	38±4.242^{a}

Values are presented as mean ± SD; values with similar superscripts are not significantly different (P>0.05); DMRT.

The result indicates significant difference (P>0.05) in water quality parameters particularly in temperature, electrical conductivity, and total dissolved solids throughout the study period. The increase in temperature (July, 31.8±7.071^{ab}) and conductivity (July, 1404±33.94^{d}) the highest over the months suggests a warming trend, while the stability in ammonia (nitrate, and phosphate levels indicates good water quality management (Table 3).

4.5 DISCUSSION

As the world's population grows, the demand for food is increasing. Urbanization and population growth are twin concerns that are exerting pressures on production resources like land, water, and nutrients due to increasing demands (Goddek et al., 2019). Genetic make-up and environmental conditions prevalent at the growing periods have been known to influence the growth characters of fish and crops (Tiamiyu *et al*., 2012). According to Table 4.1 result, significant growth occurred throughout the study period for weight gain and specific growth rate while survival rates dropped towards the end of the study due to cannibalism, poor water quality, and jumping. The result suggests that deteriorating conditions in *Carias gariepinus* breeding environments or facilities lead to mortality as a consequence of cannibalism and other causes. The finding is consistent with the study of Abdelhamid *et al.* (2010) who reported cannibalism in catfishes in a similar situation which resulted in decreased survival rates.

According to Table 2 result, the okra seedlings transplanted 6 days into the growing beds in the aquaponics system began to flower 40 days after the transplanting. The result is in line with Patwary (2001) research which revealed that okra plants took 37-39 days in soil media for first flowering. After 46 days, the first okra pods were seen in T1 and T2 while T3 delayed 2 days before producing pods. The okra pods were harvested 63 days after planted. Similarly, Olasantan and Bello (2004) noted that the time from planting to first pods and harvesting ranges from 55-62 days. It was observed that T1 had the best growth parameters and also produced the highest yield followed by T2 and T3, respectively. This is a result of T1 receiving water supply from the bio-filter first. Agba et al. (2011); Omotoso and Johnson (2015) reported the highest yield from okra is the variety with the best plant height. Similarly, Sreenivasa et al. (2010) showed that the leaves number per plant contribute greatly to promoting both growth and yield in okra. Another study was done by Umeri et al., (2018) that the total leaf area contributed significantly to the highest vegetative growth obtained hence higher fruit yield due to higher photosynthetic material accumulated. Stem girth is a significant vegetative trait that determines how resistant and susceptible a crop is to lodging conditions. According to Varmudy, (2011) okra was reported to have good girth that can withstand lodging effects. This study observed not just how good girth resists lodging but also it determines growth and yield.

On the other hand, temperature of water also plays a diametrical role, not only in reining fish's metabolic process (Battes et al., 1979) but also for vegetable production and nitrification process. Temperature fluctuated at highest (July, 31.8 ± 7.071^{ab}) and lowest (May, 26.75 ± 0.494^{a}). Dissolved oxygen (DO) is another considerable factor in fish culture although catfish is a hardy fish that can survive in a low DO content. Rakocy *et al.* (2004) observed DO values from 3.7 to 4.6 while producing okra in aquaponic system. The nitrifying bacteria growing on the root systems also participated in oxygen uptake (Sutton *et al*., 2006). Therefore, the present finding of DO (Table 3) values was suitable for okra, catfish and nitrifying bacteria in aquaponic system. The increase in temperature (July, 31.8 ± 7.071^{ab}) and conductivity (July, 1404 ± 33.94^{d}) the highest over the months suggests a warming trend, while the stability in ammonia (nitrate, and phosphate levels indicates good water quality management.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMEDATIONS

5.1 CONCLUSION

The current experiment has vividly proven that using nutrient film techniques (NFT) is suitable for fish growth and production. The aquaponics system is also favorable for okra growth and production performances as well. The system encourages the used for fish and vegetable production in urban and peri-urban areas. That being so, malnutrition and food insecurity will be mitigated with modest environmental pollution. Furthermore, it provides better opportunities to achieve the nutritional demand and accelerate the sustainable and rational use of land and water resources.

5.2 Recommendations

Based on the results, the following are recommendations to improve fish and okra performance in an NFT aquaponics system:

1. Further research should be carried out in an open environment or a green-house which provides 10 to 12 hours of light to obtain greater crop yield.
2. The fish should be stocked 3-4 months in the cultured tank before planting of crop to accumulate efficient nutrients that would accelerate growth and yield performance.
3. Over feeding must be avoided to eliminate water pollution.
4. Fish should not be overstocked to mitigate cannibalism, space limitation and influence growth.

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APPENDIX 1

Descriptive table for fish growth

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
March	Weight gain 1	2	10.84	15.33	10.84	-126.9	148.60	0.00	21.7
	Specific growth rate 2	2	10.99	15.54	10.99	-128.6	150.60	0.00	22.0
	FCR 3	2	0.71	0.00	0.00	0.7	0.71	0.71	0.7
	Protein intake 4	2	12.18	4.83	3.42	-31.2	55.57	8.77	15.6
	PER 5	2	1.24	1.75	1.24	-14.5	16.95	0.00	2.5
	Feed intake 6	2	27.07	10.73	7.59	-69.4	123.50	19.48	34.7
	Survival rate	2	99.00	1.41	1.00	86.3	111.71	98.00	100.0
	Total	14	23.15	33.93	9.07	3.6	42.74	0.00	100.0
April	Weight gain 1	2	32.07	10.17	7.19	-59.3	123.46	24.88	39.3
	Specific growth rate 2	2	24.59	2.31	1.63	3.9	45.30	22.96	26.2
	FCR 3	2	0.70	0.00	0.00	0.7	0.70	0.70	0.7
	Protein intake 4	2	31.88	5.54	3.92	-17.9	81.66	27.96	35.8
	PER 5	2	1.70	1.15	0.81	-8.6	12.05	0.89	2.5
	Feed intake 6	2	70.85	12.31	8.71	-39.8	181.47	62.14	79.6
	Survival rate	2	92.00	0.00	0.00	92.0	92.00	92.00	92.0
	Total	14	36.25	33.01	8.82	17.2	55.31	0.70	92.0
May	Weight gain 1	2	77.65	19.94	14.10	-101.5	256.80	63.55	91.7
	Specific growth rate 2	2	30.97	1.85	1.31	14.3	47.63	29.66	32.3
	FCR 3	2	0.70	0.00	0.00	0.7	0.71	0.70	0.7
	Protein intake 4	2	70.27	20.44	14.45	-113.3	253.87	55.82	84.7
	PER 5	2	1.71	0.09	0.07	0.9	2.54	1.64	1.8
	Feed intake 6	2	156.14	45.41	32.11	-251.9	564.15	124.03	188.3
	Survival rate	2	90.00	0.00	0.00	90.0	90.00	90.00	90.0
	Total	14	61.06	55.12	14.73	29.2	92.89	0.70	188.3
June	Weight gain 1	2	93.91	23.00	16.27	-112.8	300.58	77.64	110.2
	Specific growth rate 2	2	32.34	1.77	1.25	16.5	48.22	31.09	33.6
	FCR 3	2	0.70	0.00	0.00	0.7	0.70	0.70	0.7

	Protein intake 4	2	126.52	24.54	17.35	-94.0	347.00	109.17	143.9
	PER 5	2	0.96	0.07	0.05	0.4	1.55	0.92	1.0
	Feed intake 6	2	281.16	54.53	38.56	-208.8	771.12	242.60	319.7
	Survival rate	2	85.00	1.41	1.00	72.3	97.71	84.00	86.0
	Total	14	88.66	95.42	25.50	33.6	143.75	0.70	319.7
July	Weight gain 1	2	74.29	41.49	29.33	-298.4	447.02	44.96	103.6
	Specific growth rate 2	2	30.17	4.22	2.98	-7.7	68.06	27.18	33.1
	FCR 3	2	0.35	0.49	0.35	-4.10	4.80	0.00	0.7
	Protein intake 4	2	79.02	111.75	79.02	-925.01	1083.05	0.00	158.0
	PER 5	2	0.48	0.24	0.17	-1.70	2.66	0.31	0.7
	Feed intake 6	2	175.60	248.33	175.60	-2055.58	2406.78	0.00	351.2
	Survival rate	2	78.50	4.95	3.50	34.03	122.97	75.00	82.0
	Total	14	62.63	96.22	25.71	7.08	118.18	0.00	351.2

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
March	Between Groups	14344.58	6	2390.76	26.99	0
	Within Groups	620.10	7	88.59		
	Total	14964.68	13			
April	Between Groups	13869.65	6	2311.61	55.34	0
	Within Groups	292.41	7	41.77		
	Total	14162.06	13			
May	Between Groups	36619.78	6	6103.30	14.83	0.001
	Within Groups	2880.82	7	411.55		
	Total	39500.60	13			
June	Between Groups	114265.96	6	19044.33	32.43	0
	Within Groups	4110.23	7	587.18		
	Total	118376.20	13			

July	Between Groups	44425.87	6	7404.31	0.68	0.671
	Within Groups	75920.58	7	10845.80		
	Total	120346.46	13			

APPENDIX 2

Okra growth parameters

Descriptive									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
No. of leaf Wk2	Plot 1	15	3.27	0.46	0.12	3.01	3.52	3	4
	Plot 2	15	3.33	0.49	0.13	3.06	3.6	3	4
	Plot 3	15	3.47	0.52	0.13	3.18	3.75	3	4
	Total	45	3.36	0.48	0.07	3.21	3.5	3	4
Height Wk2	Plot 1	15	9.47	2.02	0.52	8.35	10.59	4.5	13
	Plot 2	15	9.07	1.70	0.44	8.13	10.01	6.5	12
	Plot 3	15	7.73	1.40	0.36	6.96	8.51	4	10
	Total	45	8.76	1.85	0.28	8.20	9.31	4	13
Leaf area WK	Plot 1	15	2.77	0.34	0.09	2.58	2.96	2	3.4
	Plot 2	15	2.63	0.23	0.06	2.50	2.76	2.2	3
	Plot 3	15	2.69	0.31	0.08	2.52	2.86	2	3.1
	Total	45	2.70	0.30	0.04	2.61	2.79	2	3.4
Girth Wk2	Plot 1	15	0.1	0.00	0.00	0.1	0.1	0.1	0.1
	Plot 2	15	0.1	0.00	0.00	0.1	0.1	0.1	0.1
	Plot 3	15	0.1	0.00	0.00	0.1	0.1	0.1	0.1
	Total	45	0.1	0.00	0.00	0.1	0.1	0.1	0.1
No. of leaf Wk 4	Plot 1	15	6.67	1.05	0.27	6.09	7.25	5	8
	Plot 2	15	6	0.76	0.20	5.58	6.42	4	7
	Plot 3	15	5.33	0.49	0.13	5.06	5.6	5	6
	Total	45	6	0.95	0.14	5.71	6.29	4	8
Height WK4	Plot 1	15	15	3.32	0.86	13.16	16.84	8	19
	Plot 2	15	16.47	3.18	0.82	14.7	18.23	11	22
	Plot 3	15	15.47	3.09	0.80	13.76	17.18	11	23
	Total	45	15.64	3.19	0.48	14.69	16.6	8	23
Leaf area WK4	Plot 1	15	7.92	2.08	0.54	6.769	9.071	5	11.5
	Plot 2	15	6.573	1.87	0.48	5.537	7.61	3	9.5
	Plot 3	15	4.8	0.90	0.23	4.3	5.3	3	6.5
	Total	45	6.431	2.10	0.31	5.8	7.063	3	11.5
Girth WK4	Plot 1	15	0.267	0.07	0.02	0.227	0.307	0.2	0.4
	Plot 2	15	0.16	0.06	0.02	0.125	0.195	0.1	0.3
	Plot 3	15	0.147	0.05	0.01	0.118	0.175	0.1	0.2
	Total	45	0.191	0.08	0.01	0.166	0.216	0.1	0.4
No. of	Plot 1	15	8.8	1.21	0.31	8.13	9.47	7	11

leaf WK6	Plot 2	15	7.87	1.13	0.29	7.24	8.49	6	10
	Plot 3	15	8.6	1.45	0.38	7.79	9.41	6	11
	Total	45	8.42	1.31	0.20	8.03	8.81	6	11
Height WK6	Plot 1	15	17.193	4.24	1.09	14.845	19.541	9	25.5
	Plot 2	15	24.32	3.82	0.99	22.206	26.434	16	30.1
	Plot 3	15	20.233	3.31	0.85	18.4	22.067	15	25
	Total	45	20.582	4.75	0.71	19.155	22.009	9	30.1
Leaf area WK6	Plot 1	15	10.147	2.60	0.67	8.709	11.584	6.5	14.7
	Plot 2	15	7.62	2.06	0.53	6.482	8.758	4	11
	Plot 3	15	7.453	2.99	0.77	5.795	9.111	0.3	13.1
	Total	45	8.407	2.81	0.42	7.563	9.251	0.3	14.7
Girth WK6	Plot 1	15	1.18	0.49	0.13	0.909	1.451	0.6	2
	Plot 2	15	0.633	0.19	0.05	0.527	0.739	0.4	1
	Plot 3	15	0.6	0.16	0.04	0.509	0.691	0.3	0.9
	Total	45	0.804	0.41	0.06	0.681	0.928	0.3	2
No of leaf WK8	Plot 1	15	10	2.93	0.76	8.38	11.62	5	15
	Plot 2	15	9.27	2.28	0.59	8	10.53	6	14
	Plot 3	15	6.8	2.15	0.55	5.61	7.99	3	11
	Total	45	8.69	2.79	0.42	7.85	9.53	3	15
Height WK8	Plot 1	15	34.73	12.27	3.17	27.94	41.53	18	55
	Plot 2	15	26.93	6.75	1.74	23.2	30.67	14	40
	Plot 3	15	26.13	5.77	1.49	22.94	29.33	17	35
	Total	45	29.27	9.40	1.40	26.44	32.09	14	55
Leaf area WK8	Plot 1	15	14.047	4.60	1.19	11.497	16.596	6	19.5
	Plot 2	15	12.413	3.05	0.79	10.727	14.1	7	17
	Plot 3	15	10.633	3.75	0.97	8.555	12.712	4.5	17.5
	Total	45	12.364	4.02	0.60	11.157	13.572	4.5	19.5
Girth WK8	Plot 1	15	1.44	0.58	0.15	1.117	1.763	0.7	2.3
	Plot 2	15	0.767	0.29	0.08	0.604	0.93	0.4	1.2
	Plot 3	15	0.74	0.20	0.05	0.632	0.848	0.4	1.1
	Total	45	0.982	0.51	0.08	0.83	1.134	0.4	2.3
Okra Yield	Plot 1	15	6.93	1.94	0.50	5.86	8.01	3	10
	Plot 2	15	6	1.69	0.44	5.06	6.94	3	9
	Plot 3	15	4.33	1.54	0.40	3.48	5.19	2	7
	Total	45	5.76	2.01	0.30	5.15	6.36	2	10

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
No. of leaf Wk2	Between Groups	0.311	2	0.156	0.653	0.526
	Within Groups	10	42	0.238		
	Total	10.311	44			
Height Wk2	Between Groups	24.711	2	12.356	4.148	0.023
	Within Groups	125.1	42	2.979		
	Total	149.811	44			
Leaf area WK	Between Groups	0.163	2	0.082	0.927	0.404
	Within Groups	3.696	42	0.088		
	Total	3.859	44			
Girth Wk2	Between Groups	0	2	0	0	1
	Within Groups	0	42	0		
	Total	0	44			
No. of leaf WK 4	Between Groups	13.333	2	6.667	10.5	0
	Within Groups	26.667	42	0.635		
	Total	40	44			
Height WK4	Between Groups	16.844	2	8.422	0.824	0.446
	Within Groups	429.467	42	10.225		
	Total	446.311	44			
Leaf area WK4	Between Groups	73.463	2	36.732	12.759	0
	Within Groups	120.913	42	2.879		
	Total	194.376	44			
Girth WK4	Between Groups	0.13	2	0.065	16.352	0
	Within Groups	0.167	42	0.004		

	Total	0.296	44			
No. of leaf WK6	Between Groups	7.244	2	3.622	2.246	0.118
	Within Groups	67.733	42	1.613		
	Total	74.978	44			
Height WK6	Between Groups	383.659	2	191.83	13.228	0
	Within Groups	609.087	42	14.502		
	Total	992.746	44			
Leaf area WK6	Between Groups	68.329	2	34.165	5.143	0.01
	Within Groups	278.979	42	6.642		
	Total	347.308	44			
Girth WK6	Between Groups	3.182	2	1.591	15.695	0
	Within Groups	4.257	42	0.101		
	Total	7.439	44			
No of leaf WK8	Between Groups	84.311	2	42.156	6.88	0.003
	Within Groups	257.333	42	6.127		
	Total	341.644	44			
Height WK8	Between Groups	677.2	2	338.6	4.428	0.018
	Within Groups	3211.6	42	76.467		
	Total	3888.8	44			
Leaf area WK8	Between Groups	87.435	2	43.718	2.943	0.064
	Within Groups	623.828	42	14.853		
	Total	711.263	44			
Girth WK8	Between Groups	4.72	2	2.36	15.191	0
	Within Groups	6.525	42	0.155		
	Total	11.246	44			

Okra Yield	Between Groups	52.044	2	26.022	8.656	0.001
	Within Groups	126.267	42	3.006		
	Total	178.311	44			

APPENDIX 3

Water quality parameters

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
March	DO 1	2	6.35	1.202	0.85	-4.45	17.15	5.5	7.2
	Temp 2	2	29	2.404	1.7	7.40	50.60	27.3	30.7
	pH 3	2	7.1	0.424	0.3	3.29	10.91	6.8	7.4
	NH3 4	2	0.04	0.000	0	0.04	0.04	0.04	0.04
	NO4 5	2	0.035	0.007	0.005	-0.03	0.10	0.03	0.04
	NO2 6	2	0.015	0.007	0.005	-0.05	0.08	0.01	0.02
	EC 7	2	731.5	81.317	57.5	0.89	1462.11	674	789
	TDS 8	2	77	36.770	26	-253.36	407.36	51	103
	PO4 9	2	0.06	0.057	0.04	-0.45	0.57	0.02	0.1
	Salt 10	2	0.25	0.014	0.01	0.12	0.38	0.24	0.26
	KH 11	2	23	1.414	1	10.29	35.71	22	24
	Total	22	79.486	213.133	45.44	-15.01	173.98	0.01	789
Apr	DO 1	2	6.35	1.768	1.25	-9.53	22.23	5.1	7.6
	Temp 2	2	29.8	4.950	3.5	-14.67	74.27	26.3	33.3
	pH 3	2	6.95	1.061	0.75	-2.58	16.48	6.2	7.7
	NH3 4	2	0.045	0.007	0.005	-0.02	0.11	0.04	0.05
	NO4 5	2	0.03	0.014	0.01	-0.10	0.16	0.02	0.04
	NO2 6	2	0.015	0.007	0.005	-0.05	0.08	0.01	0.02
	EC 7	2	1054	91.924	65	228.10	1879.90	989	1119
	TDS 8	2	136.5	24.749	17.5	-85.86	358.86	119	154
	PO4 9	2	0.015	0.007	0.005	-0.05	0.08	0.01	0.02
	Salt 10	2	0.24	0.042	0.03	-0.14	0.62	0.21	0.27
	KH 11	2	23	2.828	2	-2.41	48.41	21	25
	Total	22	114.27	307.366	65.531	-22.01	250.55	0.01	1119
May	DO 1	2	8.55	0.212	0.15	6.64	10.46	8.4	8.7
	Temp 2	2	26.75	0.495	0.35	22.30	31.20	26.4	27.1
	pH 3	2	7.3	0.141	0.1	6.03	8.57	7.2	7.4
	NH3 4	2	0.025	0.007	0.005	-0.04	0.09	0.02	0.03
	NO4 5	2	0.03	0.014	0.01	-0.10	0.16	0.02	0.04
	NO2 6	2	0.015	0.007	0.005	-0.05	0.08	0.01	0.02
	EC 7	2	1169	59.397	42	635.34	1702.66	1127	1211
	TDS 8	2	231.5	43.134	30.5	-156.04	619.04	201	262
	PO4 9	2	0.01	0.000	0	0.01	0.01	0.01	0.01
	Salt 10	2	0.24	0.014	0.01	0.11	0.37	0.23	0.25
	KH 11	2	25.5	2.121	1.5	6.44	44.56	24	27
	Total	22	133.54	342.009	72.917	-18.10	285.18	0.01	1211

June	DO 1	2	8.05	1.909	1.35	-9.10	25.20	6.7	9.4
	Temp 2	2	28.2	2.263	1.6	7.87	48.53	26.6	29.8
	pH 3	2	7.3	0.566	0.4	2.22	12.38	6.9	7.7
	NH3 4	2	0.035	0.007	0.005	-0.03	0.10	0.03	0.04
	NO4 5	2	0.03	0.014	0.01	-0.10	0.16	0.02	0.04
	NO2 6	2	0.015	0.007	0.005	-0.05	0.08	0.01	0.02
	EC 7	2	1309.5	16.263	11.5	1163.38	1455.62	1298	1321
	TDS 8	2	317	42.426	30	-64.19	698.19	287	347
	PO4 9	2	0.015	0.007	0.005	-0.05	0.08	0.01	0.02
	Salt 10	2	0.265	0.007	0.005	0.20	0.33	0.26	0.27
	KH 11	2	30	5.657	4	-20.82	80.82	26	34
	Total	22	154.58	384.868	82.054	-16.06	325.22	0.01	1321
July	DO 1	2	7.15	3.606	2.55	-25.25	39.55	4.6	9.7
	Temp 2	2	31.8	7.071	5	-31.73	95.33	26.8	36.8
	pH 3	2	6.85	1.061	0.75	-2.68	16.38	6.1	7.6
	NH3 4	2	0.04	0.014	0.01	-0.09	0.17	0.03	0.05
	NO4 5	2	0.035	0.021	0.015	-0.16	0.23	0.02	0.05
	NO2 6	2	0.025	0.007	0.005	-0.04	0.09	0.02	0.03
	EC 7	2	1404	33.941	24	1099.05	1708.95	1380	1428
	TDS 8	2	403.5	24.749	17.5	181.14	625.86	386	421
	PO4 9	2	0.015	0.007	0.005	-0.05	0.08	0.01	0.02
	Salt 10	2	0.21	0.014	0.01	0.08	0.34	0.2	0.22
	KH 11	2	38	4.243	3	-0.12	76.12	35	41
	Total	22	171.97	415.441	88.572	-12.23	356.16	0.01	1428

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
March	Between Groups	945966.3	10	94596.63	130.496	0
	Within Groups	7973.909	11	724.901		
	Total	953940.2	21			
April	Between Groups	1974851	10	197485.1	238.738	0
	Within Groups	9099.252	11	827.205		

	Total	1983951	21			
May	Between Groups	2450977	10	245097.7	499.892	0
	Within Groups	5393.311	11	490.301		
	Total	2456371	21			
June	Between Groups	3108477	10	310847.7	1623.931	0
	Within Groups	2105.585	11	191.417		
	Total	3110583	21			
July	Between Groups	3622573	10	362257.3	2157.892	0
	Within Groups	1846.631	11	167.876		
	Total	3624420	21			