CSIR COLLEGE OF SCIENCE AND TECHNOLOGY

ASSESSMENT OF PRODUCTION AND PROFITABILITY OF STOCKING SIZES AND DENSITIES OF NILE TILAPIA FOR SMALL – SCALE POND FARMING

ISAAC ADDO

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BY

ISAAC ADDO

Thesis submitted to the Department of Fisheries Science and Aquaculture of CSIR College of Science and Technology, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Aquaculture

FEBRUARY 2021

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this College or elsewhere.

Candidate's Signature…………………… Date…………………………..

Isaac Addo

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the CSIR College of Science and Technology.

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Co-Supervisor's Signature:……………………………..Date:…………………

Dr. Francis K. Y. Amevenku

ABSTRACT

The study evaluated growth performance and profitability of culturing monosex male tilapia at different stocking densities and sizes. Two stocking sizes (2 g, 10 g) and densities (3 fish/m^2, 6 fish/m^2) were respectively evaluated from January to August 2020, at Aquaculture Research and Development Center of CSIR-Water Research Institute, Akosombo. The two factorial designs have four treatments (T) as follows: 2 g at 3/m^2 (T_1), 2 g at 6/m^2 (T_2), 10 g at 3/m^2 (T_3) and 10 g at 6/m^2 (T_4). Average initial weight stocked in four ponds of 200 m^2 were 2.9 ± 0.6 g, 2.9 ± 0.6 g, 10.2 ± 2.1 g and 10.2 ± 1.7 g. All the experiments were replicated. Selected water quality parameters and experimental fish were monitored at 14 days interval. Based on calculated F-values of fixed effects for growth parameters monitored, both stocking size and density independently had significant impact on final weight, condition factor, weight gain, specific growth rate and fish survival at different probability levels. Final mean weights of fish among the treatments were significantly different ($P < 0.05$) except for T_2 and T_4. Highest to least final mean weights were 195.0 ± 18.5 g, 181.7 ± 16.3 g, 153.3 ± 27.5 g and 152.2 ± 18.8 g, respectively ranked by T_3, >T_1, >T_4, >T_2. Survival of fish was relatively higher ($P < 0.05$) for both high stocking size of 10g (87.5 %) and lower stocking density of 3 fish/m^2 (90.0 %). Temperature, pH and alkalinity were all within optimal range required by tilapia for growth except DO, NH_3-N and Turbidity which were below the optimal range. T_2 recorded highest return to variable cost of 50.05 % with T_4 been least (9.46 %). Results suggest that higher yield and profitability are achievable for small – scale Nile tilapia pond production at stocking size of 10 g with density of 3 fish/m^2 density.

KEY WORDS

Nile tilapia

Aquaculture

Stocking density

Stocking sizes

Profitability

Small – scale pond farming

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DEDICATION

To my late mother Rita Addo. Secondly, to my lovely wife, Patience Fremah Owusu, for her love, financial support and encouragement throughout the study.

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LIST OF ACRONYMS

FAO	-	Food and Agriculture Organization
MT	-	Metric Tone
MoFAD	-	Ministry of Fisheries and Aquaculture Development
MOFA	-	Ministry of Food and Agriculture
MoALF	-	Ministry of Agriculture, Livestock and Fisheries
NGO	-	Non-Governmental Organization
USD	-	United State Dollar
GIFT	-	Genetically Improved Farm Tilapia
GDP	-	Gross Domestic Product
DO	-	Dissolve Oxygen
NO_2	-	Nitrite
NH_3	-	Ammonia
CO_2	-	Carbon dioxide
$CaCO_3$	-	Calcium Carbonate
ARDEC	-	Aquaculture Research and Development Center
CSIR	-	Council for Scientific and Industrial Research
WRI	-	Water Research Institute
pH	-	Hydrogen Ion Concentration
FR	-	Feeding Rate
EPA	-	Environmental Protection Agency
BW	-	Body Weight

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CHAPTER ONE

INTRODUCTION

Background to the Study

The global trend of aquaculture is gaining importance in the world's contribution to total fish supply due to decline in capture fisheries and also the need to utilize existing inland waters for food production (De Silva & Hassan, 2007). According to FAO (2020) report, global fish production is estimated to have reached about 179 million tonnes in 2018 with a total first sale value estimated at USD 401 billion, of which 82 million tonnes, valued at USD 250 billion, came from aquaculture production. Aquaculture alone accounted for 46 percent of the total production of which 52 percent of fish produced through aquaculture were consumed by human (FAO, 2020). This clearly shows that aquaculture may be the alternative source that would meet global needs.

There has been great level of development and expansion in almost all regions of the world with African and Asia almost doubled during the last 20 years (FAO, 2020). There has been improvement in feed formulation and better culture facilities such as ponds and cages (Munguti, Kim, & Ogello, 2014). According to Béné & Heck (2005), fish serves as food and provides nutritional security to about 200 million people in Africa. However, the continent is yet to report any significant additions of aquaculture on the world ordered series, even though there are many available natural resources in many regions of the continent (FAO, 2010).

Freshwater fishes dominate global aquaculture production (FAO, 2012) of which the Nile tilapia, *Oreochromis niloticus* is the most consumed and the second most cultured fish species worldwide and first in Ghana (Sarpong *et al*., 2005). The fisheries resources of Ghana supply 60 – 70 % of natural animal protein to the people (Aggrey-Fynn, 2001). Generally, many Ghanaians are encouraged to take more of fish protein than meat because fish is nutritious and healthy (Asmah, 2008).

Fish stands out as the most important in terms of food security because its price, relative to the price of other high – quality protein sources such as milk, meat and eggs is quite affordable (FAO, 2020). Furthermore, it is an important source of healthy long-chain omega-3 fatty acids, essential amino acids, vitamins (particularly A, B and D) and minerals such as iron, calcium, zinc and selenium. This unique nutritional composition means that fish represents a valuable source for healthy dietary diversification, even in relatively small quantities (FAO, 2020).

Fish farming in Ghana is comprised largely of small-scale farmers who practice on a subsistence basis using the intensive and semi-intensive systems of production in cages and earthen ponds respectively (Asase, 2013). Ghana presently has about 5,000 fish farmers operating approximately 19,000 fish ponds and cages (MOFA, 2012).

Commercial fish farmers who use intensive culture systems, though in the minority produce about 75 percent of Ghana's total aquaculture production (Rurangwa, Agyakwah, Boon, & Bolman, 2015; MOFAD, 2016). Most of this fish produced are either consumed directly or sold locally (Anane, 2018) with harvest sizes ranging from 50 g to about 400 g. Less than 30 % of the farmers are able to produce tilapia larger than 200 g (Cobbina, 2010).

Small-scale aquaculture provides more employment opportunities per unit of capital investment than larger farms (Pillay & Kutty, 1990). In addition, it is widely distributed geographically and are locally owned, enabling income distribution among the population (Pillay & Kutty). The most common and versatile structures for culturing Nile tilapia have been earthen ponds (Bardach, Ryther, & McLarney, 1972) and is the most popular method of growing tilapia. One advantage is that the fish are able to utilize natural foods. Management of tilapia ponds ranges from extensive systems, using only organic or inorganic fertilizers, to intensive systems, using high-protein feed, aeration and water exchange.

Body size is an important factor affecting the growth and energy budget of fish (Jobling, 1994), and most studies have suggested that the relative growth rate decreases with increasing body size (Jobling, 1994). The stocking size of tilapia for grow-out pond production has been dictated by the common size of fingerlings available from tilapia hatcheries. For instance, since 2 g is the common and readily available fingerling sizes, farmers tend to stock directly into grow-out ponds (Remedios, Eddie, Jun – Rey, Sugue1, & Christopher, 2002). The body size of fish also depends on the number of fish that are stocked initially per unit area. It is one of the most important factors in determining the productivity of a fish farm (El-Sayed, 2006). Stocking density influences survival, growth, behavior, health, water quality, feeding and production (Lesvia, 2014). Therefore, increased stocking density can reduce yield. Increased stocking density increases competition among fish for space and access to feed and thus reduce growth (Quiros, 1999). Furthermore, increased stocking density can compromise water quality and growth in fish ponds. The optimum stocking density is the level where the maximum yields are reached and the choice of stocking density depends partly on economic factors and market demands. Increased stocking density may reduce the mean size of fish at harvest. Therefore, a farmer may choose to stock at suboptimal densities for yield to produce large size (Aksungu & Aksungur, 2007).

Statement of the Problem

Fish is a vital component of human food supply and most important source of high-quality animal protein (Tidwell, 2012). According to FAO (2007), global inland fishery resources appear to decline as a result of habitat degradation and overfishing and this trend is unlikely to be reversed. The only other source for the human population to produce fish is aquaculture.

Fish is an important food product in Ghana, accounting for 60 % of the national dietary animal protein and about 75 % of the total domestic fish production is consumed locally (Rurangwa *et al.*, 2015). Presently Ghana is not self-sufficient in fish production (Cobbina, 2010) because the demand for fish is higher than supply. Currently 25 % of domestic fish consumption is being imported and the demand will continue to increase due to increasing of population growth (Cobbina, 2010). The situation of net deficit is thus expected to worsen in time and aquaculture production is expected to play a key role in ensuring food security by increasing progressively to bridge that deficit. Unfortunately, aquaculture in Ghana is mostly done on subsistence basis with very few commercial operators. According to Gitonga, Mbugua, & Nyandat, (2004), most people in Ghana see aquaculture as part-time, limited investment hobby due to the poor regard they have for aquaculture as an economic activity.

In commercial fish production, bigger size fingerlings are thought to survive better, grow faster, and reach market size sooner (Arce & Lopez, 1981) as compared to smaller size. Acquiring small-sized fingerlings may require a two staged production system where fry from hatcheries are transferred to nursery ponds and then stocked into grow-out ponds when they attain the weight of about 10 – 20 g. Body size is an important factor affecting the growth and energy budget of fish (Jobling, 1994), and the stocking size of tilapia for grow-out pond production has been dictated by the common size of fingerlings available from tilapia hatcheries. Studies revealed that majority (85 %) of small - scale farmers stocked their cage and ponds with tilapia fry of sizes 2 g instead of the recommended fingerlings size of at least 15 g (Beveridge, 2004). Karikari & Asmah (2016) and Asmah, Abban, Ofori, & Awity, (2014) reported lower stocking sizes, ranging from 2.0 to 5.0 g by tilapia cage farmers in Lake Volta in Ghana. According to authors, majority of farmers use 2 g fingerlings and only few farmers stock using 5 g.

Although many works have been done on Nile tilapia pond culture, production characteristics of pond culture of Nile tilapia with a nursery phase to produce stocker-size and fingerlings have not been evaluated (Agyakwah, 2020). There is still the need to study in detail the different stocking sizes of Nile Tilapia (*O. niloticus*) in relation to different stocking densities that will result in higher production with minimal cost at small – scale level in pond. Therefore, this work aims at evaluating the production and profitability of different stocking sizes and densities of Nile Tilapia (*O. niloticus*) in small – scale pond farming in Ghana.

Purpose of the Study

Fisheries resources provide food, income and employment for people in many parts of the world (Bledar, 2007). In Africa, aquaculture industry is largely underdeveloped, dominated by small – scale farmers in rural and remote areas. The dominance of small – scale aquaculture is due to the goal set for aquaculture development; that of food security with less emphasis on profit maximization (Kaunda, 2015).

Ghana is full of rivers, seas, dams, and dugouts, all of which make aquaculture practicable countrywide (Béné, 2007). High demand for fish makes the country great for aquaculture development (Amenyogbe, Gang, & Zhongliang, 2018). This is because the country is blessed with good topography and climate, copiousness human resources and an abundance of natural water bodies that makes aquaculture possible. Upon all these enormous potentials, Ghanaian fish farmers and fishers are unable to meet the fish requirements of the country, leading to a deficit in supply (Asmah, 2008). This could be due to inadequate supply of tilapia fish seeds and most farmers obtained tilapia seed from less desirable sources such as fish production ponds of other farmers that have not been drained for several years (FAO, 2009). Meanwhile, tilapia has become one of the most important and highly demand protein source in the rural and urban centers of Ghana (Rurangwa *et al.*, 2015). With reduction in foreign exchange, fish importation can be partly replaced by fish from aquaculture. Couple with the declining marine fisheries and inland fisheries under pressure, aquaculture is being promoted to supply the shortfall (Rurangwa *et al.*, 2015). This work, therefore, is to evaluate the suitable stocking size and stocking density that would lead to higher yield with manageable cost of the entire production in a small – scale ponds.

Research Objectives

The main objective of this study was to evaluate growth performance and profitability of producing monosex male Nile tilapia (*O. niloticus*) at different stocking densities and sizes in earthen ponds. Specifically, the study sought to:

1. Compare the growth performance and survival of different stocking sizes and densities of tilapia fingerlings within similar/same time frame
2. Determine the effects of water quality characteristics at different stocking sizes and densities.
3. Determine the cost effectiveness of *O. niloticus* production at different stocking sizes and densities.

Hypothesis

Ho: There are no relative differences in growth performance of O. *niloticus* fingerlings stocked at different sizes and densities in a small - scale pond farming.

H_1: There are relative differences in the growth performance of O. *niloticus* fingerlings stocked at different sizes and densities in a small - scale pond farming.

Ho: The water quality characteristics of small – scale pond culture of *O. niloticus* fingerlings stocked at different sizes and densities are the same.

H_1: The water quality characteristics of small – scale pond culture of *O. niloticus* fingerlings stocked at different sizes and densities are not the same.

Ho: The profitability of small – scale pond culture of *O. niloticus* fingerlings stocked at different sizes and densities is the same.

H_1: The profitability of small – scale pond culture of *O. niloticus* fingerlings stocked at different sizes and densities is not the same.

Significance of the Study

This research work would provide current information for farmers to establish the best stocking size and density of fingerlings that are economically viable for small – scale commercial pond fish farming. It will also contribute to knowledge on effective stocking sizes and densities of Nile Tilapia for small – scale pond farming, which should inform hatcheries and potential nurseries of their expected products to grow out pond farmers.

Delimitation

Rearing of Nile Tilapia is very common in Akosombo zone of the Eastern Region of Ghana. The research is however narrowed to the production of *O. niloticus* and its profitability on different stocking sizes and densities. It also focuses on only small-scale pond farming.

Limitations

Due to limited number of functional ponds, replicates of ponds were limited to two (2). Rapid heating and high evaporation of pond water as a result of intense dry season resulted in fish diseases and mortality in some treatment ponds. Due to limited labour support, all the seven thousand and two hundred (7200) individual fish were not measured at the same of harvest. Therefore, average weights of samples of 100 individual fishes for each replicate per treatment were used to estimate yield per pond.

Definition of Terms

Profitability

Profitability is a business's ability to produce a return on an investment based on its resources in comparison with an alternative investment.

Stocking density

Stocking density refers to initial quantity or mass of fry or fingerlings stocked per unit of water volume or area of pond.

Stocking Size

Stocking sizes refers to starting weight or length of fish (fry or fingerlings) that are stocked in production ponds.

Small – Scale Pond farming

Small-scale pond farming is the production of aquatic organisms in a limited number of earthen ponds, without using advanced and expensive technologies. It is usually characterized by low skill and labour input, whereas products are supplied to the local or surrounding markets.

Organisation of the Study

The research work is organized and presented in five (5) chapters. Chapter one which is the introductory aspect of the work consists of the background to the study, statement of the problem, purpose of the study, objectives of the study, specific objectives of the study, hypothesis, significance of the study, limitations and delimitations, definition of terms, organization of the study and the chapter summary.

Chapter two looks at literature related to the study. It consists of the theoretical framework as well as empirical basis of the study which was obtained from different sources including the internet and libraries. Chapter three focuses on the Methodology of the study: Area of the study, experimental set-up, stocking of fingerlings, experimental design, feeding and determination of growth parameters such as specific growth rate. The profitability of the study on benefit – cost ratio, profit index and return on investment was dealt with under this chapter.

Chapter four briefly describes and discusses the results of the study. Chapter five dealt with summary, conclusions, and recommendations whiles the rest were list of references and appendices showing the various test analysis that was conducted.

Chapter Summary

Nile tilapia (*Oreochromis niloticus*) is the major tilapia species cultured in Ghana. Most of the fish produced are either consumed directly by fish farmers or sold locally. Generally, small-scale pond aquaculturist provides more employment opportunities per unit of capital investment than those with larger farms (Pillay & Kutty, 1990). Ghana is full of rivers, seas, dams, and dugouts, all of which make aquaculture practicable countrywide (Béné, 2007).

Over several decades, pond production has been very low, contributing only insignificant proportion of national fish supplied, and less than 10 % of cultured Nile Tilapia in Ghana (Ofori, 2000; Rurangwa *et. al*., 2015). This research work, therefore, is to assess the suitable stocking size and density that would lead to higher yield with manageable cost of the entire production in a small – scale pond farming.

CHAPTER TWO

LITERATURE REVIEW

General Overview of Tilapia Production

According to FAO 2018 report, global aquaculture production (including aquatic plants) in 2016 was 110.2 million tonnes, with the first-sale value estimated at USD 243.5 billion (FAO, 2020). Aquaculture continues to grow more rapidly than all other animal producing sectors. Developing countries ‟contribution by weight increased from 73 % in 1979 to 90 % in 1998 (FAO, 2006). However, this dramatic increase in production is skewed on a regional basis in favour of Asia (Amenyogbe *et al.*, 2018). For example, in 1998, aquaculture productions by weight per regions were as follows: Europe, about 5 %; South America, less than 2 %; Africa and Oceania, about 0.5 % each (FAO, 2006). In the next ten (10) years (2020 – 2030), the world population would grow by a further 2 billion people to around 12 billion. This will lead to an increased demand for food. If an increase in food prices is to be prevented, food production needs to increase proportionally (Rosegrant, Paisner, Meijer, & Witcover, 2001). According to the World - Fish Centre (2005), the supply of fish in Africa is in crisis. The Sub-Saharan African (SSA) region is the only region of the world where there is no notable increase in per capita supply or per capita fish consumption in the world. Fish production peaked at about 171 million tonnes in 2016, with aquaculture representing 47 percent of the total and 53 percent of non-food uses (including reduction to fishmeal and fish oil).

Tilapia, which is native to Africa and Middle East, has emerged from hidden to one of the most productive and internationally traded food fish in the world. The farming of tilapias in its crudest form is believed to have originated more than 4,000 years ago from Egypt. The first recorded scientifically oriented culture of tilapia was conducted in Kenya in 1924 and soon spread throughout Africa. Tilapia was later transplanted and became established as a potential farmed species by the late 1940s in the Far East and a decade later spread in the Americas (WFC, 2005). The last three decades have seen significant developments in farming of tilapias worldwide. Due to the increasing commercialization and continuing growth of tilapia industry, the commodity is not only the second most important farmed fish globally, next to carps but is also described as the most important aquaculture species of the 21^{st} Century (Shelton, 2002). The fish is being farmed in about 85 countries worldwide (FAO, 2002) and about 98 % of tilapia produced in these countries is grown outside their original habitats (Shelton, 2002) in Asia with the introduction of Mozambique tilapia (*Oreochromis mossambicus*). Early experience in culture of the species was met with failure due to its undesirable characteristics and production of small, low value fish at harvest. Success in tilapia farming began in the latter half of the 20^{th} Century after introductions of better performing tilapia species from Africa and development of techniques to manage unwanted reproduction. (WFC, 2005).

Pond culture is the most popular method of growing tilapia and one advantage is that the fish are able to utilize natural foods. Pond-based tilapia farmers in Bangladesh, China, Taiwan, Thailand and Vietnam use the polyculture system while in the Philippines, most farmers grow tilapias under the monoculture system. Culture methods followed in these countries vary depending on nature of farmland and farmers' capacity to invest. For example, in Bangladesh most farmers do not use commercial feeds and in Vietnam, farmers use only a small quantity of commercial feeds. On the other hand, in China, Taiwan, Thailand and the Philippines most farmers fertilize their ponds and feed the fish with formulated pellet feeds (World Fish Center, 2005).

According to Dey and Paraguas (2001), the overall average yield of pond farming in Taiwan is very high (12 to 17 mt/ha) while ponds in Bangladesh, China, Philippines, Thailand and Vietnam produce around 1.7, 6.6, 3.0, 6.3 and 3.0 mt/ha, respectively. Guerrero (2001), however claimed that in Philippines, the semi-intensive culture of *O. niloticus* in earthen ponds (0.25 - 1 ha, 1 meter depth) yields 4-8 mt (average size of 150-250 g) per crop in 3-4 months with 80-90 % survival. In Egypt, earthen pond aquaculture is the major type of culture system where only wastelands are allowed to be used for fish mainly because of their salt and alkali content and poor drainage. Semi-intensive aquaculture, which is done mostly in ponds, provides about 75 % of the country's total aquaculture production (about 64,000 mt) and most farms are in northern or eastern part of the Nile Delta (Alceste & Jory, 2002). In Israel, sex-reversed male *O. niloticus* and *O. aureus* hybrids are polycultured in earthen ponds with carp or monocultured in plastic-lined ponds at a high stocking density. Pelleted feeds and aeration are widely used due to high stocking density. Most tilapias produced are larger than 400 g at harvest (Popma & Lovshin, 1996). Culture in freshwater ponds using the semi-intensive system is the practice of most commercial farmers in Brazil, Colombia, Costa Rica and Mexico and most countries in Africa as well. Polyculture of tilapias with shrimps is another practiced in Latin America, especially in Ecuador and Peru.

Genetic improvement through selective breeding has been used for millennia on crops and livestock, but up until the 1980s, little had been done to utilize this process for farmed fish. In response to the inadequate supply of tilapia seed and its deteriorating growth performance, World Fish Center and partners began the Genetic Improvement of Farmed Tilapia (GIFT) project to develop a faster-growing strain of Nile tilapia (*Oreochromis* niloticus) that was suitable for both small-scale and commercial aquaculture (WFC, 2015).

In Ghana, currently, the Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR) in partnership with WorldFish, has developed the "Akosombo" Tilapia strain, using selective breeding which grows 30 % faster than non-improved tilapia (Rurangwa *et al*., 2015).

African Tilapia Production in Pond

There is potential fish demand driven by population and economic growth in Africa where tilapia is a native species favoured by most consumers. There is also a big potential for fish farming with 37 % of its surface area suitable for artisanal and 43 per cent suitable for commercial fish production (Jamu, 2001).

Aquaculture, especially of tilapias, has the potential to play a leading role in the fight against food insecurity, malnutrition, and poverty in Africa (Béné & Heck, 2005). Aquaculture for food production in Africa was introduced over 50 years ago (Machena & Moehl, 2001).

Tilapias were successfully produced in ponds for the first time in Democratic Republic of Congo (DRC) in 1946 (Vincke, 1995). By the end of the 1950s, there were almost 300 000 ponds in production in Africa (Satia, 1989).

The production of tilapia was geared towards the production of food for local consumption and for the diversification of rural activities related to agriculture and animal husbandry. Soon after its first expansion, tilapia culture made no further progress and has, in many cases, even declined, resulting in the abandonment of fish farms by discouraged farmers (De Graaf, 2004). This failure has been attributed to (i) the harvesting of too many small stunted tilapia from over-populated ponds because of the use of poor husbandry techniques; (ii) the dependency on subsidized extension services and fingerling distribution centers; (iii) misjudgment of the motivation of the rural fish farmers by policy makers, and the creation of the myth that the rural farmer will willingly take up fish farming for food security or as a source of protein for their family; and (iv) failure to apply adequate resources, which may be naturally limiting such as water and feed (Alceste & Jory, 2002).

Aquaculture in Africa is primarily small-scale rural (this component estimated at 95 % of total production), characterized by one or more small (i.e. 100 to 500 m^2) ponds, integrated into the mosaic of agricultural activities (FAO, 2017). Earthen ponds are the most important small – scale, monoculture at household level of tilapias, contributing about 38 to 93 % of total tilapia production in Africa. Productivity varies from 0.5 mt/ha/yr in extensive small-scale fishponds to 16 mt/ha/yr in commercial ponds (Jamu, 2001). The species used is mostly *O. niloticus.* Apart from *O. niloticus*, other species such as *T. zillii* and *O. rendalli* are also cultured. Small-scale pond culture of tilapias is usually integrated with other agricultural enterprises such as vegetables, rice and other field crops. These systems produce twice as much income as non-integrated ponds and are reportedly more sustainable (Jamu, 2001). However, farming tilapias in ponds on a large scale on a semi-intensive basis also exist in some countries of Africa such as Egypt, Zambia and Cote d'Ivoire.

Ghana's Aquaculture Industry

Ghana is blessed with Lake Volta, one of the largest artificial lakes in the world (FAO, 2005). Eighty percent (80 %) of overall aquaculture production is derived from tilapia production in Ghana (FAO, 2017). It is a delicacy for both the middle and lower class and are consumed by most religious groups nationwide (Asmah, 2008). Because fish is the most preferred and widely consumed animal protein in Ghana, its annual per capita consumption was estimated to be at 26 kg compared with the global average of 20 kg (FAO, 2020). The fisheries sector of Ghana provides livelihood support to about 2.4 million people and contribute 1.5 % to the nation's gross domestic product (Asiedu *et al.*, 2017).

Development of aquaculture in Ghana over the years has been by two different approaches. One has to do with the target of communities for adoption of communally owned and managed ponds. This was a means of generating benefits in the form of fish for nutrition and cash to communities to reduce poverty. This method was adopted in Ghana when aquaculture started in the country around 1950s (Cobbina, 2010). It is currently practiced in almost all the sixteen regions in the country, most prominently in the southern and central belts. The other one is to bridge the gap between demand and supply of fish and to produce in excess for exports (Amenyogbe *et al*., 2018). The main fish species cultivated are the O. *niloticus* which constitutes over 90 % of aquaculture production (Kassam, 2014). The catfishes (*Clarias spp.* and *Heterobranchus spp.)* and *Heterotis niloticus* account for the remaining 10 % (Rurangwa *et al*., 2015). Aquaculture production contributes substantially to the national economy through creation of employment, improving the gross domestic product (GDP), enhancing foreign exchange, serving as food security and poverty reduction.

The best land and water resources for pond aquaculture are located in the southern parts of the country, but districts that are considered otherwise unsuitable have irrigation schemes that provide additional opportunities for fish farming (Kapetsky *et al*., 1991; Asmah, 2008). Lake Volta provides by far the most abundant surface freshwater for cage and pen aquaculture. Additionally, 5 percent of freshwater irrigation sites in the country are targeted for aquaculture (Fisheries Commission, 2012).

The participation of commercial investors in the aquaculture sector has neutered the face of aquaculture in Ghana leading to the launching of numerous cages in Volta Lake (Kassam, 2014). Although these fishes are highly cherished and consumed by many locals, their culture is not as high as tilapia. The presence of these fish in Ghanaian water bodies is a good indication of potential culture which may be tapped to create employment and food security and improve local economies. The aquaculture subsector consists of many operators who pattern on a subsistence level which use the semi-intensive system to culture fish in earthen ponds. Other farmers employ the extensive culture system by the use of dams, dugout, ponds, and reservoirs for fish culture in Ghana (Koranteng, Bortey, & Yeboah, 2006).

Currently in Ghana, the prevailing culture system for tilapia production has changed, and the immense bulk of cultured tilapia is now cultured intensively in cages, especially in Lake Volta whiles at the same time government of Ghana has embarked on numerous programs to construct dugouts and dams to provide a reliable source of water in each constituency within the country (Asase, 2013).

Pond Culture in Ghana

The aquaculture subsector consists of many operators who pattern on a subsistence level which use semi-intensive system to culture fish in earthen ponds. Majority of farmers also employed the extensive culture system by the used of dams, dugout, ponds, and reservoirs for fish culture (Koranteng, *et al*., 2006). After – independence in 1957, the government espoused a policy to construct fishponds within all irrigation system in the country most especially in the northern part of the country (Kassam, 2014). Aquaculture started with pond culture, and this type of aquaculture is still prevalent in Ghana presently (Prein & Ofori, 1996) where the bottom and sides of the ponds are built with concrete. Pond culture is the most popular method of growing tilapia in the southern and central part of the country, which covers about 98 percent of farms, which is also primarily small scale and semi-intensive in status (Kaunda, Abban, & Peacock, 2010).

Pond culture is usually used because there are several advantages and this includes ability of the fish to utilize the natural foods within the pond. Management of tilapia ponds ranges from extensive systems, using only organic or inorganic fertilizers, to intensive systems, using high-protein feed, aeration and water exchange. Nile tilapia is cultured primarily in the semi-intensive ponds based on fertilizers or in integrated systems with livestock (Edwards, 1986). Pond sizes are chosen according to the aim of the production unit and the land available for development. Ponds can be found from fry ponds of a few hundred square metres to 100 hectare extensive production ponds. They are also differentiated according to fry rearing ponds, fingerling ponds, fattening ponds and market size production (Laâszloâ, Gizella, & Chris, 2002).

Challenges with Pond Culture

Maintaining good pond culture is crucial for growing healthy fish, achieving satisfactory production and improving culture efficiency. High yield and profit in fish culture completely depends on proper management. Under good management however, there are several technical difficulties which may arise during fish culture with possibility of large-scale loss of production (Ajmal, Choudhury, Vinay, & Gupta, 2016).

Some of the problem's farmers face include poor site selection, bad pond designing and construction, inefficient pond management, shortages of fingerlings, lack of fertilizers, feeds, lack of harvesting strategies, marketing and processing (Prein & Ofori, 1996). Most of the farmers lacked technical information, access to credit facility for pond construction, lacked access to quality fingerlings, faced poaching by others and lacked nets for harvesting (FAO, 1990). Furthermore, Owusu, Attipoe, & Padi (1999), highlighted other major constraints faced by Ghanaian pond farmers of which some included inadequate extension services, lack of fish seeds, inadequate manufactured feeds, lack of capital for expansion and lack of biotechnical information.

According to De Silva (1993), Ghana has over 1500 small scale pond farmers who find commercial feeds too expensive forcing them to produce their own feed on-farm, using locally available ingredients such as cocoa pod husk, palm kernel cake and copra cake. Whilst most of the ingredients used are proven to be viable, they are not produced under strict hygienic conditions which naturally affect the final product.

There are virtually no supply lines from the hatcheries to the other parts of the country, where pond farmers are located and the farmers are responsible for transporting their feed and fingerlings from the hatcheries and purchasing centers to their farms adding up to the operational costs (Konyim, 2018).

Nurseries and supply vans are therefore needed to provide better services to many pond farmers who are beyond the easy reach of the hatcheries (Konyim, 2018).

Species Cultured in Pond and their Sources

Almost all types of aquatic animals can be grown in ponds but they are best suited for animals that tolerate a relatively wide range of environmental conditions (Teichert – Coddington, Popma, & Lovshin, 1997). This is most obvious in the context of water temperature, the most important environmental factor affecting aquaculture production.

Rakocy and McGinty (1989) reported that tilapia is frequently cultured with other species to take advantage of the many natural foods available in ponds as well as to control a secondary crop of the tilapia to allow the original stock to attain a larger market size. The species mostly used in polyculture include tilapia (*O. niloticus*), catfish (*Clarias sp*.), *Heterotis sp*. and snakehead (*Parachanna sp*.). Monoculture practices involved stocking with all male, sex-reversed, hand sexed or both sexes of tilapia. The numerous small and medium-scale operators rely on fingerlings that are available from several hatcheries - among them are Tropo Farm, Crystal Lake, Fish Reit and from a selected line of *Oreochromis niloticus* produced at the Aquaculture Research and Development Centre (ARDEC) in Akosombo (Asase, 2013).

Stocking Size and Density of Tilapia Production in Pond

The stocking density and stocking size are important indicators that determine the economic viability of pond production system (Aksungu & Aksungur, 2007). The stocking density of fish in ponds describes the number of fish that are stocked initially per unit area. It is one of the most important factors in determining the production of a fish farm (El-Sayed, 2006). Open pond stocking rates for tilapia can vary considerably depending on the needs of the fish culturist and the production methods employed.

Ponds that are only supplemented with manures, grains or grain by – products, the fishes are usually stocked at a maximum rate of 1 per square meter of surface area but where tilapia are fed pelleted feed the stocking density could be as high as 3-4 fingerlings per square meter of surface area. At these densities, aeration becomes necessary. (Williams, 2000)**.**

Lanuza (2000), studied the effect of different stocking sizes on the growth, yield and survival of Nile tilapia in ponds. It clearly showed that there was no significant difference in stocking sizes ranging from 0.10 to 1.20 grams after 90 days of culture. Bigger size fingerlings have been found to survive better, grow faster, and reach market size sooner (Arce & Lopez, 1981).

Production of fingerlings may require a two – stage system where fry from hatcheries is transferred to nursery ponds and then stocked into grow-out ponds to attain a desirable weight such as 10 to 20 g. The small - sized fingerlings can also be stocked directly into the grown – out pond for culture (Remedios *et al.*, 2002). The stocking size of tilapia for grow-out pond production has been dictated by the common size of fingerlings available from tilapia hatcheries. The regular size of the fingerlings sold by most hatcheries in Ghana is 2.5 g (Konyim, 2018). Due to high demand, smaller sized fingerlings are often sold, which have lower survival rates (Konyim, 2018). The stocking density and sizes of fish pond have also been found to depend on the culture practices that accommodate single or special combination of fish species for a particular purpose.

In mono-sex culture where only single sexes are reared in pond with high quality water management (Rakocy & McGinty, 1989) could lead to high productivity. Stocking rate have been found to vary from 4,000 to 20,000 per acre (4046.86 m^2) with frequent culture stocking rate of 8,000 per acre (4046.86 m^2) for the period of 200 days or more to reach average weight of 500 g. In mixed – sex culture, tilapias are usually stocked at low rates to reduce competition for food and promote rapid growth (Rakocy & McGinty).

Importance of Water Quality in Pond Production of Nile tilapia (*O. niloticus*)

Water quality is the first most important limiting factor in pond fish production and most difficult production factor to understand, predict and manage (Boyd, 1984). Fish depend totally on water for breathing, feeding and growing, excrete wastes, maintain a salt balance, and reproduce. Aquaculture ecosystems involving pond fish culture is composed of physical, chemical and biological factors that interact individually and collectively to influence fish performance (Schmittou, 2006). The key water quality variables related to tilapia culture in pond are temperature, dissolve oxygen (DO), nitrite (NO_2), ammonia (NH_3), hydrogen ion concentration (pH), turbidity and total alkalinity of the water (Abolude, 2007). However, other parameters such as nitrates, phosphates, and hardness also have significant impacts within aquaculture production systems (Abolude, 2007).

Temperature

Temperature is most important for fish and other aquatic life in the pond and can vary greatly throughout the pond, with surface water affected more by air temperature than deeper water. It is always the best to match the types of fish stocked in a pond with the existing temperature regime (Bryan, William, Tom, 2006).

In general, the rates of chemical and biological reactions are usually doubled for every 10 °C increase in temperature. This means that aquatic organisms will use twice as much dissolved oxygen at 30 °C as at 20 °C and chemical reactions will progress twice as fast at 30 °C than at 20 °C (Thomas & Michael 1999). Therefore, dissolved oxygen requirements of fish are more critical in warm waters than in cold water. Chemical treatments of ponds are also influenced by temperature. For example, fertilizers dissolve faster at high temperature in pond (Boyd & Craig 1998). Tilapia stop feeding when water temperature falls below 16 °C or 17 °C and reproduction is best at water temperatures higher than 27 °C and does not occur below 20 °C. In subtropical regions within a cool season, the number of fry produced always decrease when daily average water temperature is less than 24 °C (Thomas & Michael).

Work done by Thomas and Micheal (1999) reveal that, after 16 to 20 day spawning cycles with 227 g Nile tilapia, fry recovery was about 600 fry per female brooder at a water temperature of 28 °C, but only 250 fry per female at 24 °C. Preferred water temperatures for tilapia growth are approximately 29 °C to 31 °C. When fish are fed to satiation, growth at the preferred temperature is typically three times greater than at 22 °C. Maximum feed consumption at 22 °C is only 50 to 60 %. Tilapias reportedly tolerate temperatures up to 40 °C, but stress-induced disease and mortality are problematic when temperatures exceed 37 or 38 °C (Popma & Leonard, 1995).

The optimal temperature for growth of tilapia ranges from 29 ^{o}C to 31 ^{o}C. Growth declines greatly with decreasing temperature and at 20 ^{o}C to 22 ^{o}C, growth is about 30 % of optimum (Teichert-Coddington *et al.*, 1997). The lethal minimum temperature for most species of tilapia is 10 ^{o}C or 11 ^{o}C while at 37 ^{o}C to 38 ^{o}C stress and diseases tend to attack most of them (Popma & Leonard, 1995).

Dissolve oxygen

Dissolved oxygen is a critical water quality variable in fish culture, so the fish farmer should be familiar with the dynamics of dissolved oxygen concentrations in ponds (Boyd, 1990). The maximum amount of oxygen that can be dissolved is usually controlled by the water temperature (Bryan *et al.*, 2006).

Tilapias are highly tolerant of low dissolve oxygen concentration, even down to 0.1 mg/l (Magid & Babiker, 1975) but it will depend on the stocking density. The Optimum dissolve oxygen concentration for better growth for *O. niloticus* should be greater than 3 mg/l (Ross, 2000).

Low dissolved oxygen is usually the first water quality parameter that constraint growth of fish in intensively managed ponds and the commonly cultured species of tilapia survive routine dawn dissolved oxygen concentrations less than 0.5 mg/l, levels considerably below the tolerance levels for most other cultured fish. The survival is due to their ability to extract dissolved oxygen from the film of water at the water-air-interface (Popma & Leonard, 1995). Low dissolved oxygen levels are critical to tilapia and are responsible for more fish kills, either directly or indirectly, than all other problems combined (Schmittou, 2006) and this is because fish aerobic metabolism requires dissolved oxygen (Timmons, James, Wheaton,, Summerfelt, & Vinci, 2001).

Although dissolved oxygen will diffuse into water, its rate of diffusion is quite slow therefore, photosynthesis by phytoplankton is the major source of dissolved oxygen in a fish culture system especially during the day with good sunlight (Boyd, 1984). A study conducted by Thomas and Michael (1999) indicated that Nile tilapia grew better when aerators were used to prevent morning dissolve oxygen concentrations from falling below 0.7 to 0.8 mg/l as compared with unaerated control ponds. Tilapia can survive acute low dissolve oxygen concentrations for several hours, but the ponds should be managed to maintain dissolve oxygen concentrations above 1 mg/l (Thomas & Michael, 1999) so as to ensure better growth.

Hydrogen ion concentration (pH)

The pH of a pond is a measure of the acidity of the water. Farm ponds in valleys underlain by limestone will usually have a pH of 7.0 to 8.5 (Bryan *et al.*, 2006). Regular monitoring of pH in pond culture is an essential part of the operation of semi - intensive freshwater – fish culture systems. Tilapia seem to grow best in water that has pH value of 7 (neutral) or 9 (alkaline) (Ross, 2000). Ponds with a pH less than 6.0 may result in stunted or reduced fish populations (Bryan *et al.*, 2006). The pH in fish ponds fluctuates depending on the CO_2 levels in water. pH increases during the day because algae and plants remove CO_2 from water through photosynthesis while at night when photosynthesis stops the CO_2 levels increase again making the pH to drop. This cycle is repeated every 24 hours. Fluctuations in CO_2 concentration and pH tend to increase with increasing biomass of fish (Tucker & D'Abramo, 2008).

Ammonia level

Ammonia is the principal nitrogenous product of fish metabolism and originates from the deamination of amino acids. Ammonia reaches pond water as a product of fish metabolism and decomposition of organic matter by bacteria (Boyd, 1984). It slows growth rates and sometimes increases mortality in fish culture when ammonia level is highly concentrated (El-Sherif & El-Feky, 2009). Too high ammonia levels can also lead to stress and damages to gills and other tissues of tilapia**.** Fish exposed to low levels of ammonia over time are more susceptible to bacterial infections, poor growth. High density can lead to high concentration of ammonia in a pond (Floyd & Watson, 2012). Ammonia toxicity is closely correlated with pH and, to a lesser extent, water temperature and dissolve oxygen. At pH 7 less than 1 % of the total ammonia is in the toxic un-ionized form; at pH 8, about 5 to 9 % is unionized, at pH 9, 30 to 50 %, and at pH 10, 80 to 90 %. Consequently, ammonia toxicity is more problematic in poorly buffered ponds (Popma & Leonard, 1995).

According to Popma and Leonard (1995), massive mortality of tilapia occurred within a couple of days when there was sudden transfer of tilapia to water with unionized ammonia concentrations greater than 2 mg/l. However, when acclimated to sub-lethal levels, approximately half of the fish survived. Unionized ammonia depresses appetite of tilapia at concentrations as low as 0.08 mg/l.

Turbidity

Turbid pond water is usually only an aesthetic problem. It is frequently caused by runoff from disturbed areas around the pond or from bottom-dwelling fish and muskrats (Bryan *et al.*, 2006). It can also be due to growth of phytoplankton and human activities such as construction. Mining can lead to high sediment levels entering water bodies during rain storms (EPA, 2005).

Turbid water is very common in new ponds and usually disappears as vegetation grows around the pond (Bryan *et al.*, 2006). Any increase in turbidity affects light penetration and therefore, can affect primary production, hence oxygen concentration, and temperature. These, in turn, can have sub-lethal effects on fishes (James, Reed, Miller, & Pence, 1978). Bruton (1985), reviewed the effects of turbidity on fish, and concluded that the most important effects were: (i) reduction in light penetration and consequent photosynthesis resulting in reduced food availability and plant biomass, (ii) reduced visibility of pelagic prey, (iii) reduced availability of benthic food owing to smothering, (iv) clogging of gillrakers and (v) gill filaments and reduced areal predation risk (Bruton, 1985). High turbidity has also been shown to affect a reduction in hatching success (Rosenthal & Alderdice, 1976), egg survival (Cambray, 1983; Wilber, 1983), feeding efficiency (Moore & Moore, 1976; Vinyard & O'Brien, 1976; Brusven & Rose 1981; Gardner, 1981), growth rate (Crouse, Callahan, & Malweg, 1981), and population size (Wilber, 1983).

Total alkalinity

The term total alkalinity refers to the total concentration of bases in water expressed as milligrams per liter of equivalent calcium carbonate (Bryan *et al.*, 2006). Joseph, Richard, & Daniel, (1993), also explains it as the measurement of carbonate and bicarbonate ions (ions are atoms or groups of atoms with a negative or positive charge) dissolved in the water.

The tilapias most used in commercial culture are freshwater species, but all are tolerant to brackish water. *O. niloticus* is the least saline tolerant of the commercially important species, but grows well at salinities up to 15 ppt. (Popma

& Leonard, 1995). As the amount of carbon dioxide fluctuates, the pH of water changes and the magnitude of this shift is determined by the water's ability to absorb acids and/or bases. Photosynthetic activity in a poorly buffered pond can lead to increase in pH level usually from as low as six in the morning to nine or more by late afternoon. (Joseph *et al.*, 1993). Waters with total alkalinities of 20 to ISO mg/l contain suitable quantities of carbon dioxide to permit plankton production for fish culture. Carbon dioxide is often in low supply in waters with more than 200 to 250 mg/ l of total alkalinity (Boyd, 1984). Alkalinity remains relatively constant in ponds, but decreases steadily in non-supplemented, recirculating systems. Alkalinity can be increased by adding agricultural limestone to ponds or sodium bicarbonate to recirculating systems (Joseph *et al.*, 1993).

Nitrite

The sources of nitrite in fish ponds have not been definitely identified. However, the most likely source is the reduction of nitrate to nitrite in anaerobic muds (Boyd, 1984). According to Durborow, David, & Brunson (1997), nitrite usually enters a fish culture system after feed is digested by fish and the excess nitrogen is converted into ammonia, which is then excreted as waste into the water. Regardless of the source, ponds occasionally contain nitrite concentrations of 0.5 to 10 mg/l (Boyd, 1984). High nitrite concentrations in ponds occur more frequently in the raining season when temperatures are fluctuating, resulting in the breakdown of the nitrogen cycle due to decreased plankton and/or bacterial activity (Durborow *et al.*,1997).

Catfish and tilapia, for example, are fairly sensitive to nitrite, and trout and other cool water fish are sensitive to extremely small amounts of nitrite (Durborow *et al.*, 1997). Compared with other inorganic nitrogen compounds, it is also the least toxic. However, high levels can affect osmoregulation, oxygen transport, eutrophication and algal bloom (Lawson, 1995).

Major Constraint in the Ghanaian Pond Production System

Constraints of pond production system are considered as any factor or subsystem that works as a bottleneck to restrict the fish farmers from achieving their production potentials from pond system. Pond production system in Ghana is faced with several constraints and notable among these include poor site selection, bad pond designing and construction, inefficient pond management, shortages of fingerlings, lack of fertilizers, feeds, lack of harvesting strategies, marketing and processing (Prein & Ofori, 1996).

Abdoulie (2010), highlighted some of the major constraints of Ghanaian fish farmers as cited in Owusu *et al.* (1993). These were inadequate extension service, lack of fish seeds, inadequate manufactured feeds, lack of capital for expansion and lack of biotechnical information. In addition, some work on description and assessment of fish farms in Ghana (FAO, 1990) of which 24 farms were selected. In the findings, the constraints were: lack of credit for pond construction, lack of technical information, high cost of equipment, lack of fingerlings of *C. gariepinus* and *H. bidosalis*, and lack of proper nets for harvesting. All these constrain contribute to the cost of production.

Another critical challenge for the pond culture production is inadequate supply of tilapia fish seeds (Rurangwa *et al.*, 2015). Most farmers obtained it from less desirable sources such as fish production ponds of other farmers that have not been drained for several years and other common sources like reservoirs and rivers (FAO, 1990). Usually, these fingerlings are of very poor quality and high mortality rates making production relatively inefficient (Rurangwa *et al.*, 2015).

Predators like frogs, snakes and birds cause problems in fish ponds by eating the young fish in the pond (Marilyn, 1976). These increase the mortality rate of the fish pond thereby reducing the profit margins of the production.

CHAPTER THREE

MATERIALS AND METHODS

Study Area

This study was carried out at the Aquaculture Research and Development Centre (ARDEC) of CSIR-Water Research Institute (CSIR-WRI), Ghana ($6^{0}17'00''$ N; $0^{0}03'29''$ E) at Akosombo in the Eastern Region of Ghana (Figure 1). The study was conducted between December 2019 and August, 2020.

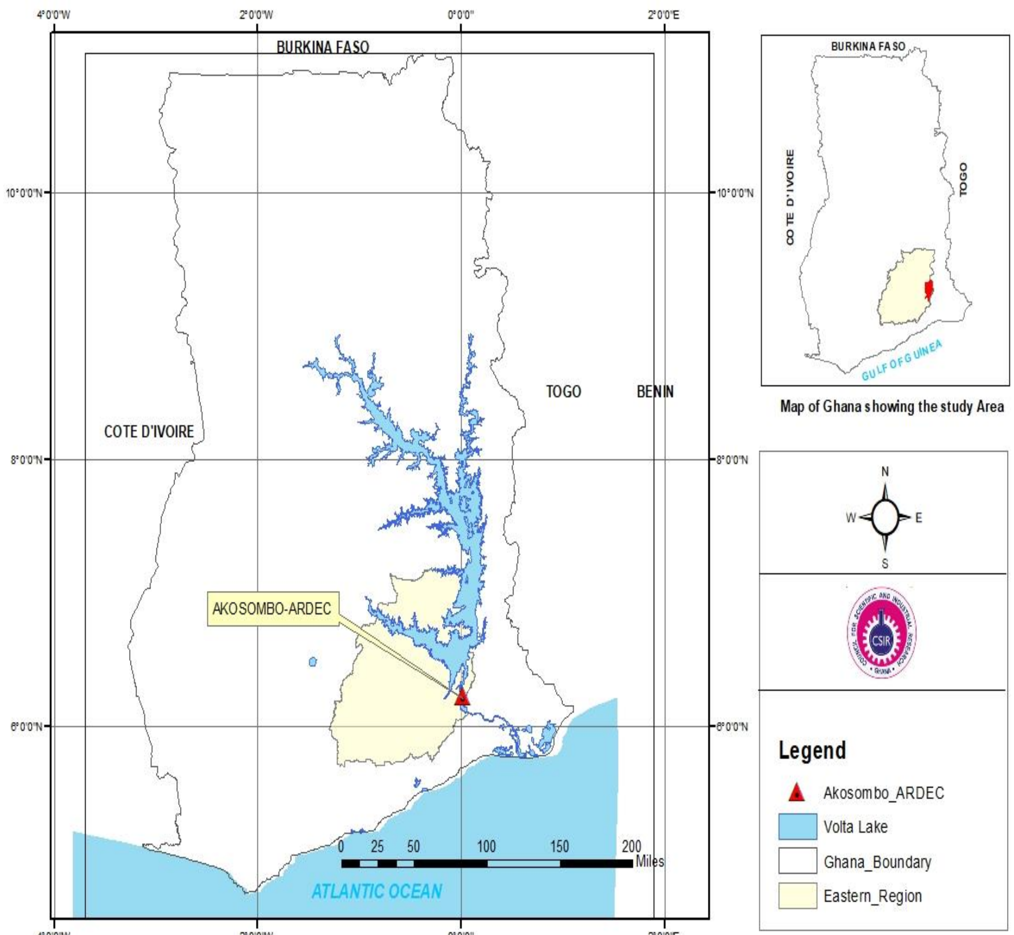

Figure 1: Map of Ghana showing the study area and site of experiment

Experimental Set-up

Eight ponds, each of size 200 m^2 was used in the study. All ponds were prepared by clearing and allowing the bottom to dry prior to use. Lime ($CaCO_3$) of 0.1 kg/m^2 was used to condition each pond prior to filling with water (Figure 2). This was done to neutralize acidity in the upper layer of the bottom soil and to increase concentrations of total alkalinity and total hardness in the water (Thomaston & Zeller, 1961). It is also to eliminate conditions that may encourage the survival of disease-causing organism (Laâszloâ *et al.*, 2002). The ponds were supplied with water screened from the Volta Lake (Figure 3). Water levels of ponds were topped up to replace losses due to evaporation and seepage.

Figure 2: Liming of pond with $CaCO_3$.

Figure 3: Filling of the pond with water screened from the Volta Lake.

Experimental Design and Stocking of Fingerlings

Mono sex male of *O. niloticus* fingerlings of the eleventh generation (G11) of "Akosombo Strain" developed by CSIR-WRI at ARDEC, Akosombo through selective breeding (Attipoe, 2006) were stocked in the experimental ponds (Figure 4). The 2 × 2 factorial study design involved a total of 7200 fingerlings of two different stocking sizes (2 g and 10 g) that were stocked at two different stocking densities (3 fish/m^2 and 6 fish/m^2) in eight ponds (Table 1). The fingerlings were allowed to acclimatize for five days before the trial commenced. Mortalities encountered during this period were replaced. All stocked fingerlings were cultured for 154 days.

Table 1 - *Number of Fish Stock in Experimental Ponds at Varying Stocking Sizes (2.9 ± 0.6 g and 10 ± 2.1 g) and Densities (3 and 6 fish per m^2)*

Stocking Sizes (g)	Stocking Densities (fish/m^2)				Total
	3 fish /m^2		6 fish /m^2		
	Pond	Total	Pond	Total	1800
2	AI	600	C1	1200	1800
	A2	600	C2	1200	1800
10	B1	600	B1	1200	1800
	B2	600	D2	1200	7200
Total		2400		4800	7200

Source: Field data (2020)

Figure 4: Stocking experimental ponds with fingerlings

Feeding and Growth Monitoring

Fish were fed with commercial extruded feed (Raanan). Forty percent (40 %) crude protein of feed with pellet size 2.5 mm at an initial rate of 8 % of fish body weight (BW) were administered to experimental ponds (A1, A2, C1, C2) (Table 1) for the first two weeks. While 40% crude protein feed (2.5 mm) at an initial rate of 6 % of fish body weight (BW) as suggested by MOALF (2014), were administered to experimental ponds B1, B2 and D1 and D2 (Table 1) for the first two weeks.

The fish were fed three times daily (8:00 a.m., 12:00 p.m. and 4:00 p.m.) and was done by hand broadcasting (Figure 5). The feeding was carried out each day within the week with one day off to help improve the culturing environment of the fish (Price and Morris, 2013).

The feeding rate (FR) was determined using the formula below;

FR = % body weight × Biomass

Where biomass = average weight × total number of fish. (MOALF, 2014). Adjustment of the amount of feed was done every two weeks as fishes increased in size.

Figure 5: Hand broadcasting of fish feed in experimental pond.

Fish Sampling

Fifty individual fish in each pond were sampled randomly once every two weeks using drag net (Figure 6). The individual standard length (SL), total length (TL) and weight were taken using measuring board and digital weighing scale respectively (Figure 7). Each fish was then returned into the pond after sampling.

Figure 6: Sampling of fish using drag net in experimental pond

Figure 7: Taking of fish length and weight from experimental pond

Water Quality Monitoring

Water quality parameters were monitored prior to stocking and bi-weekly thereafter to determine possible influences of the environment on fish growth. Water temperature, Dissolve Oxygen (DO), Nitrite (NO_2), Ammonia (NH_3), Hydrogen Ion Concentration (pH), Turbidity and Total Alkalinity of the water were all analyzed at CSIR – WRI – ARDEC Lab at Akosombo.

Measurement of water temperature

Temperature was measured *in-situ* with a digital thermometer. The meter probe was immersed into the pond water to a depth of about 20 cm (Figure 8). The temperature was read and recorded in degrees Celsius (^{o}C) to one decimal place after about two minutes. Repeated measurement was done twice and the average recorded.

Figure 8: *In-situ* measurement of water temperature in pond

Determination of dissolve oxygen (DO)

The Dissolve Oxygen was determined by Winkler Method as used by Asase, (2013). Samples of the water were carefully collected into DO bottles to exclude air and bubbling. The bottles were filled till they overflowed and was transported to the lab immediately. Two (2) ml each of Manganous Sulphate ($MnSO_4$) and Alkali – iodide azide solutions were added. The bottles were then closed with stoppers and inverted several times to mix. It was then allowed to precipitate leaving clear supernatants at the top.

Two (2) ml of concentrated Sulphuric acid (H_2SO_4) was then added, and shaken until the precipitates completely dissolved. One hundred (100) ml of the solution was measured into a conical flask and titrated with 0.0125 M sodium thiosulphate ($Na_2S_2O_3$) solution to get a pale straw colour. Ten drops of 2 % aqueous starch indicator solution were added to get blue-black colour. The titration was continued till the point (end point) when the blue-black colour first disappeared.

Dissolved Oxygen concentration in water was then calculated as follows:

Dissolved Oxygen (DO) [mg /l] = (A x M x 8000) / V

Where A = volume (ml) of titrant, M = Molarity of $Na_2S_2O_3$ and V = volume (ml) of sample used.

Determination of hydrogen ion concentration (pH)

Test tube was filled to the 5 ml mark with sample water taken from the experimental ponds. Ten drops of wide range indicator solution were added to the sample. It was capped and shaken to mix thoroughly. The colour of water in the test tube was matched with the closest colour in a comparator. The pH with the closest colour was recorded as the reading for the sample.

Determination of nitrite

Nitrite was determined by measuring 25 ml of water sample from the experimental ponds into 30 ml test tube and 25 ml of distilled water into a separate test tube (i.e. the blank). Nitriver 3 nitrite reagent was added to both, and mixture vigorously shaken for one minute, after which they were left undisturbed for five minutes reaction period. The spectrophotometer was set up and programmed to analyze nitrite at 507 nm wavelength. It was then zeroed with distilled water. The reading for the blank and sample were determined afterwards. The difference between the two values was the actual amount of nitrite of the sample (m/l).

Determination of ammonia- nitrogen (NH_3-N)

A sample cell was filled to the 10-ml mark with the water sample and a second cell with deionized water to the 10 ml mark. The contents of one ammonia salicylate powder pillow were added to each cell and shaken to dissolve the contents. The spectrophotometer programmed number for ammonia analysis was keyed in and set at 655 nm wavelength. A three – minute reaction period was allowed then the contents of one ammonia cyanurate reagent powder pillow were added to each cell, and mixture shaken to dissolve the contents. The instrument timer was started for a 15 – minute reaction period after which the blank was wiped and it was inserted into the cell holder. The instrument was zeroed and the sample was wiped and inserted into the cell holder to read the result in mg/l.

Determination of total alkalinity

In measuring total alkalinity, a clean delivery tube was inserted into a 1.600 N sulfuric acid titration cartridge attached to a titrator. The delivery knob was turned to eject air and a few drops of the sample was titrated. The counter was reset to zero and the tip was wiped. A sample volume of 100 ml was measured with a graduated cylinder and transferred into a clean 250 ml Erlenmeyer flask. Phenolphthalein and Bromcresol Green-Methyl Red Indicator powder were added in turns and each mixed thoroughly. Titration was continued with sulfuric acid to a light pink colour. The digits displayed on the counter were recorded as alkalinity in mg/l.

Determination of turbidity

The absorptometric method was used. A 25 ml of the sample was poured into a sample cell and another sample cell was filled with 25 ml of deionized water as blank. The sample was then read at a wavelength of 450 nm in Nephelometric Turbidity Units (NTU).

Determination of Growth Characteristics

Growth parameters of the fingerlings were estimated bi – weekly from sampled fish of each pond. The data collected on the fish weight and length after each sampling were used to determine growth performance in terms of, weight gain (WG, in grams), specific growth rate (SGR, g/day), condition factor (CF, g/cm^3), feed conversion ratio (FCR), feed efficiency (FE, in %) and the survival per pond.

Determination of survival per pond

Survival per pond (pond survival) was calculates as

Survival per pond (pond survival) = $\frac{number\ of\ fish\ harvested\ per\ pond}{number\ of\ fish\ stocked\ per\ pond}. \times 100\%$ (Ricker, 1975).

Determination of weight gain

The weight gain was calculated as

Weight gain (WG, in grams) = $\left(\frac{pond\ final\ weight}{number\ of\ fish} - \frac{pond\ initial\ weight}{number\ of\ fish}\right)$

Where 'pond final weight' is the final average weight per pond (g/fish) and 'pond initial weight' is average initial stocking weight per pond (g/fish) (Ricker, 1975).

Determination of specific growth rate

Specific growth rate (SGR, g/day) was determined using the formula below:

SGR (g/day) = $100 \times \left(\frac{\ln(pond\ final\ weight)}{number\ of\ fish} - \frac{\ln(pond\ initial\ weight)}{number\ of\ fish}\right) \div \Delta T$

Where, ΔT = culture period in days. (Ricker, 1975).

Determination of condition factor (CF)

Individual condition factor (CF, g/cm3) was calculated as:

$$\frac{weight\ of\ fish}{length\ of\ fish^3} \times 100$$

Where weight of fish is the final individual weight and length of fish is final individual total length. CF = condition factor (Ricker, 1975).

Determination of feed conversion ratio

The FCR is simply the amount of feed it takes to grow a kilogram of fish. A low FCR is a good indication of a high – quality feed. FCR is a valuable and power tool that allows a farmer to estimate the total feed required in growing cycle (Asase, 2013). Feed conversion ratio was calculated as:

$$FCR = \frac{\frac{dry\ feed\ intake}{number\ of\ fish}}{\frac{pond\ final\ weight}{number\ of\ fish} - \frac{pond\ initial\ weight}{number\ of\ fish}}$$ (Pillay, 1990).

Determination of feed efficiency ratio

Feed efficiency can be defined as feed conversion ratio (FCR), which is the amount of feed consumed per unit growth, or alternatively, by its inverse, the feed efficiency ratio (FER), i.e., growth per unit of feed consumed. Feed efficiency ratio is the inverse of the FCR (Halver & Hardy, 2002). It was calculated as:

Feed efficiency ratio (FE, in %) = $\frac{live\ weight\ gain\ per\ pond}{total\ feed\ fed\ per\ pond} \times 100$.

(Pillay, 1990).

Determination of Profitability of Fish production

At the end of the study, the revenue was calculated from sale of fish produced. Sales revenue is the cash value obtained for the production cycle. To arrive at sales revenue in cash, the total quantity of fish sold was multiplied by the unit price of harvested fish. It was then computed as $TR_i = P_i\ Q_i$ where P_i = price of fish per kilograms (kg), Q_i = quantity of fish harvested in kilogram (kg), TR_i = total revenue (Wood, 1999). All fish was sold at the market price. Variable costs for the production included cost of fingerlings, feed, liming and labour. It was assumed that other fixed costs such as salaries, utilities (electricity, water, telephone, and general maintenance costs), and pond construction are the same for all treatments.

The net income which is the difference between the total revenue and total cost for production results in net income or profit was computed as $\Pi = TR_i - TC_i$ where TR_i = total revenue, TC_i = total cost, Π = profit. The return on variable cost (ROC) was determined as (Profit / Variable cost) × 100 %. This ratio measures the ability of management of the farm to generate adequate returns on the capital invested by owners of the farm. The higher it is, the better (Wood, 1999).

Data Analysis

Data were analyzed using R software version 4.0.3 (R Core Team, 2020). Individual data were used to determine some parameters (initial weight, final weight, and condition factor), while for other parameters only the mean (average) value for each pond was used (WG, SGR, FCR, and FE). All data information on individual fish were included in the analyses. For all parameters, *p*-values in type III Sum of Square ANOVA were calculated using package 'car' (Fox and Weisberg, 2019). Differences were deemed statistically significant at $p < 0.05$. The growth pattern of fish for both treatments was presented in line graph using Microsoft Excel, 2013.

Data on individual fish

All parameters for which there were individual values; final weight and condition factor (CF), were analyzed using the following linear model (Model 1):

$$\boldsymbol{y_{ijk}} = \boldsymbol{\mu} + \boldsymbol{stocking\ weight_i} + \boldsymbol{stocking\ density_j} + (\boldsymbol{stocking\ weight} \times \boldsymbol{stocking\ density})_{ij} + \boldsymbol{e_{ijk}} \qquad \textbf{(Model 1)}$$

where, $\boldsymbol{y_{ijk}}$ is individual value for final weight and CF of the $\boldsymbol{k^{th}}$ fish, $\boldsymbol{\mu}$ is the population mean, $\boldsymbol{stocking\ weight_i}$ is the fixed effect of the two stocking weight (2 g and 10 g), $\boldsymbol{stocking\ density_j}$ is the fixed effect of the two stocking density (3 and 6 fish/m^2), $(\boldsymbol{stocking\ weight} \times \boldsymbol{stocking\ density})_{\boldsymbol{ij}}$ is the fixed effect of the $\boldsymbol{ij}$ interaction of stocking weight (2 and 10 g) and stocking density (3 and 6 fish/m^2), and $\boldsymbol{e_{ijk}}$ is the random residual term.

Data on individual pond

Initially, mean values per pond for WG, SGR, FCR, and FE were analyzed using a model with the same effects as Model 1. The 'stocking weight × stocking density' interaction was found significant only for WG, therefore it was analyzed using a model (Model 2) with the same effects as Model 1. The interaction was not significant for SGR, FCR, and FE, hence removed from the model. Mean value per pond for SGR, FCR, and FE was therefore analyzed using the following linear model (Model 3)

$$y_{ijk} = \mu + \textbf{stocking weight}_i + \textbf{stocking density}j + e_{ijk} \qquad (\textbf{Model 3})$$

where, y_{ijk} is mean value of SGR, FCR, and FE for the k^{th} pond, and other effects are the same as in Model 1.

Survival per pond

Survival rate per pond (pond survival) was analyzed using two models. First, a logistic regression model with the same effects as Model 1 was used. The interaction was not significant hence removed from the model. Therefore, pond survival was analyzed using the following logistic regression model (Model 4)

$$y_{ijk} = \mu + \textbf{stocking weight}_i + \textbf{stocking density}j + e_{ijk} \qquad (\textbf{Model 4})$$

Where, y_{ijk} is the logit link function of survival in the k^{th} pond, and other effects are the same as in Model 1. All values were transformed from the logit scale to the response scale. Second, arcsine transformation of pond survival permits the use of a linear model with the same effect as Model 1. The effects of the 'stocking weight × stocking density' interaction and the stocking weight alone were not significant, and were removed from the model. Arcsine-transformed pond survival was analyzed using the following linear model (Model 5)

$$y_{ij} = \mu + stocking\ density_{ij} + e_{ij} \qquad (Model\ 5)$$

Where, yij is the arcsine-transformed survival of the j^{th} pond, and other effects same as in Model 1.

CHAPTER FOUR

RESULTS

Fish Growth Parameters

Fish growth pattern

Results of growth performance of *O. niloticus* at different stocking densities and sizes is presented in Table 2 and the growth patterns are shown in Figures 10 and 11. The mean final weight of fish recorded in all four treatments was significantly different ($p < 0.05$). T_3 recorded the highest final mean weight of 195.0 ± 18.5 g, followed by 181.7 ± 16.3 g, 153.3 ± 27.5 g and the least 152.2 ± 18.8 g, for T_1, T_4 and T_2 respectively (Figure 9). The effects on the stocking sizes and densities on the final weight were highly significant ($p < 0.001$) that is 20.7 and 202.6 respectively as shown in Table 3. The effects on their interaction between the stocking sizes and densities were also significant (Table 3).

The 10 g fish size recorded higher condition factor value (2.1 ± 0.3) than the 2 g stocking size fish (2.0 ± 0.2) ($p < 0.05$) (Table 2). Similarly, fish in treatment ponds with 6 fish/m^2 recorded higher condition factor values than those stocks at 3 fish/m^2 (Table 2). Though there were significant differences in both the stocking sizes and density as shown in Table 2, there were no effects on their interaction as shown in Table 3.

Table 2 - *Mean ± Standard Deviation for Initial Weight, Final Weight, and Condition Factor (CF) of Two Stocking Weight (2 = 2 g, 10 = 10 g) at Two Stocking Densities (3 = 3 fish/m^2, 6 = 6 fish/m^2)*

Stocking Weight (g)	Stocking Density (fish/m^2)	# of Fish	Initial Weight (g)	Final Weight (g)	Condition Factor
2	3	100	2.9 ± 0.6^a	181.7 ± 16.3^b	
	6	100	2.9 ± 0.6^a	152.2 ± 18.8^c	
10	3	100	10.2 ± 2.1^b	195.0 ± 18.5^a	
	6	100	10.2 ± 1.7^b	153.3 ± 27.5^c	
2	-				2.0 ± 0.2^b
10	-				2.1 ± 0.3^a
-	3				2.0 ± 0.2^b
-	6				2.1 ± 0.3^a

Data within the same column with different superscript letters are significantly different *($p < 0.05$)*.

Source: Field data (2020)

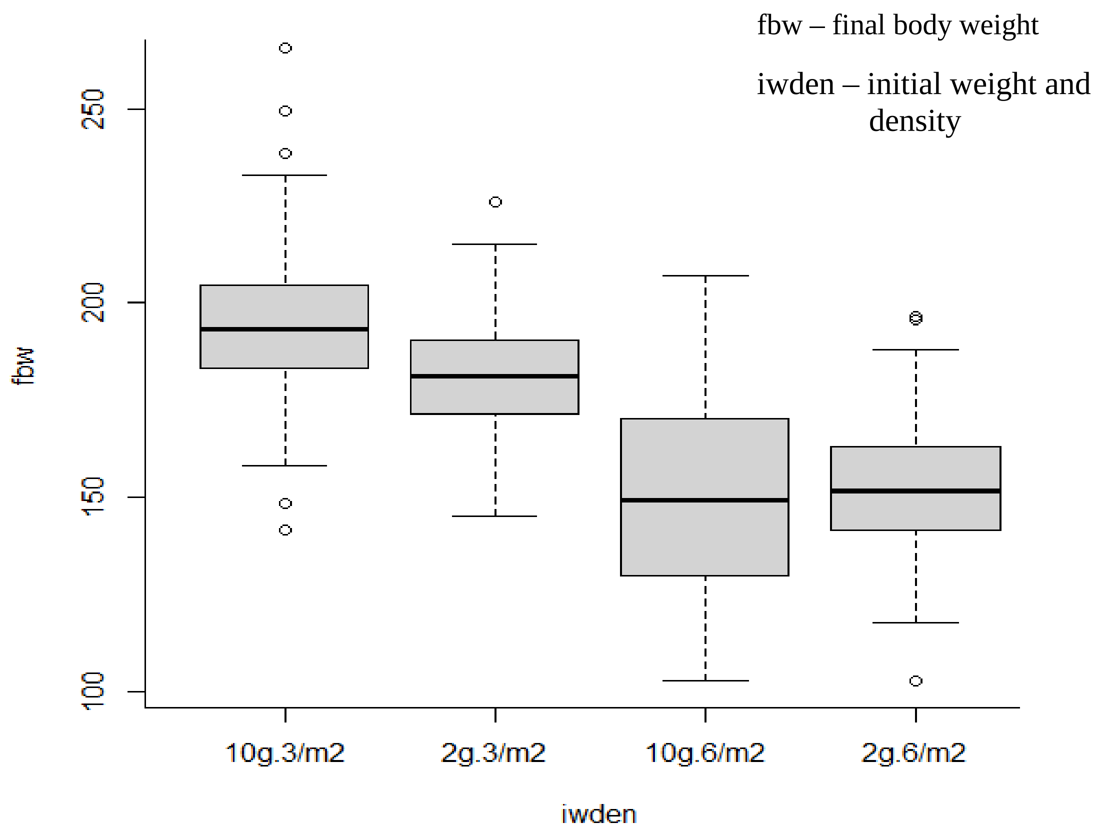

Figure 9: Boxplot of final weight of two stocking weight (2 and 10 g) at two stocking densities (3 and 6 fish/m^2) in experimental ponds.

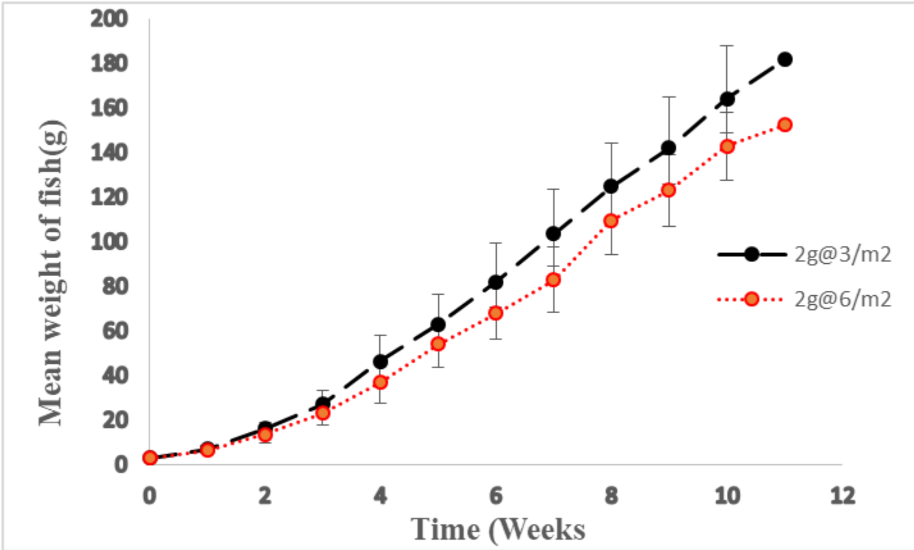

Figure 10: Growth performance of 2g stocking size of Nile Tilapia at two different stocking densities (3 and 6 fish/m^2) in experimental pond

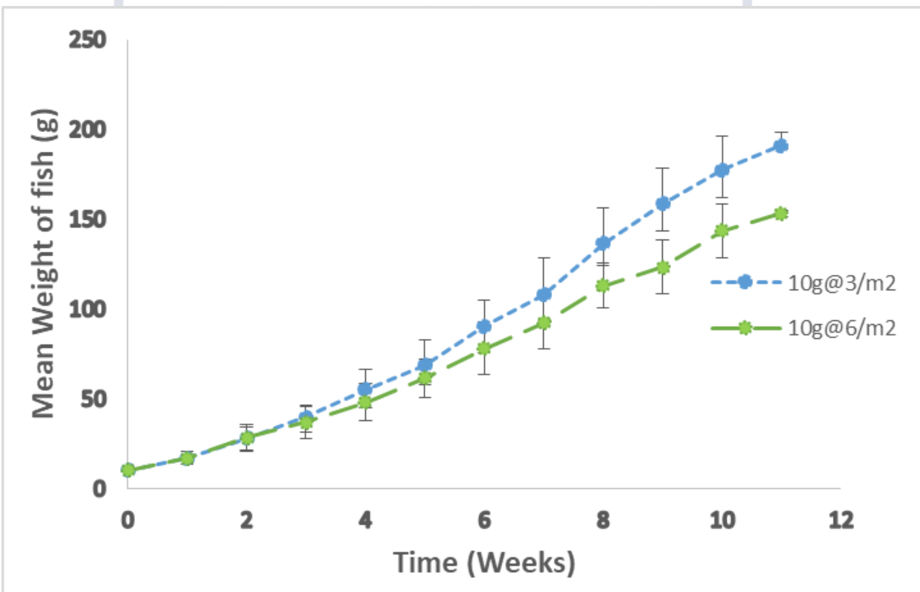

Figure 11: Growth performance of 10g stocking size of Nile Tilapia at two different stocking densities (3 and 6 fish/m^2) in experimental ponds.

Table 3 - *F-values of Fixed Effects for Growth Parameters of Different Stocking Sizes and Densities*

Effect†	FW	CF	WG	SGR	FCR	FE	SUR (logistic Regression Model)	SUR (Linear Model), Arcsine-transformed)
Stocking Weight	20.7***	4.7*	14.2***	2478.5***	2.6^{NS}	2.5^{NS}	8.6*	-
Stocking Density	202.6***	14.5***	335.6**	66.3***	4.4^{NS}	4.1^{NS}	10.3*	0.04*
Stocking Weight×Stocking Density	8.8**	-	29.3**	-	-	-		-

Significant levels are indicated as $^{***} = p < 0.001$, $^{**} = p < 0.01$, $^{*} = p < 0.05$ and NS = Not significant.

Note:

FW – Final weight

CF – Condition factor

WG – Weight gain

SGR – Specific growth weight

FCR – Feed conversion ratio

FE – Feed efficiency

SUR – Survival rate

Source: Field data (2020)

Weight gain

The highest weight gain (184.8 ± 1.5 g) was recorded by the 10g @ 3/m^2 treatment followed by 2 g @ 3/m^2 with the 10 g @ 6/m^2 recording the least weight gain values of 143.1 ± 2.0 g. There were highly significant effects ($p < 0.001$) on the stocking sizes, stocking densities and their interaction as shown in Table 3.

Specific growth rate (SGR)

The 2 g fish recorded a higher mean specific growth rate value of 2.6 ± 0.1 g/day than that of 10 g fish stocking size (Table 4). There were significant differences ($p < 0.05$) between two stocking size as shown in Table 4. Similarly, the 3 fish/m^2 recorded a higher mean specific growth rate value of 2.3 ± 0.4 g/day than 6 fish/m^2 stocking density (2.2 ± 0.5 g/day). There were significant differences ($p < 0.05$) between two stocking size as shown in Table 4. There were highly significant effects ($p < 0.001$) in SGR between the stocking densities and sizes with no significant effect on their interaction as shown in Table 3.

Feed conversion ratio (FCR)

There were no significant differences ($p > 0.05$) between the different stocking densities as well as the interaction between them for FCR (Table 3). Though the 10 g fish size recorded higher mean FCR value of 1.3 ± 0.1 than the 2 g fish size of 1.2 ± 0.1, there was no significant difference ($p > 0.05$) between them. Similarly, mean FCR values of 1.3 ± 0.1 and 1.2 ± 0.1 respectively for stocking densities 3 fish/m^3 and 6 fish/m^3, did not differ significantly ($p > 0.05$) (Tables 3 and 4).

Feed efficiency (FE)

The 2 g fish size recorded higher feed efficiency of mean value 85.6 ± 7.4 % more than the 10 g fish of 79.8 ± 5.1 % but there were no significant differences between the sizes. On the other hand, the 6 fish/m^2 stocking density recorded higher mean feed efficiency value of 86.4 ± 6.6 % than the 3 fish/m^2 of 79.0 ± 4.9 % as shown in Table 4. There was no significant effect on the stocking sizes and densities as shown in Table 3.

Survival per pond

For the logistic regression model, the 10 g stocking size recorded the higher mean survival value of 87.5 % than 2 g stocking size of 85.0 % whiles the 3 fish/m^2 stocking density had the highest survival value of 90.0 % than the 6 fish/m^2 (82.5 %). There were significant differences between stocking sizes and densities as shown in Table 4, but no significant effect on their interactions as shown in Table 3.

Table 4 - *Mean ± Standard Deviation for Growth Parameters Based on Average Values for Experimental Ponds of Two Stocking Weight (2 = 2 G, 10 = 10 G) at Two Stocking Densities (3 = 3 fish/m^2, 6 = 6 fish/m^2)*

Stocking Weight (g)	Stocking Density (fish/m^2)	# of pond	WG	SGR	FCR	FE	SUR (Logistic Model)	SUR (Linear Model, arcsine-transformed)
2		4	-	2.6 ± 0.1^a	1.2 ± 0.1^a	85.6 ± 7.4^a	85.0^b	-
10		4	-	1.8 ± 0.1^b	1.3 ± 0.1^a	79.8 ± 5.1^a	87.5^a	-
	3	4	-	2.3 ± 0.4^a	1.3 ± 0.1^a	79.0 ± 4.9^a	90.0^a	1.13^a
	6	4	-	2.2 ± 0.5^b	1.2 ± 0.1^a	86.4 ± 6.6^a	82.5^b	0.97^b
2	3	2	178.8 ± 1.5^a	-	-	-	-	-
	6	2	149.3 ± 1.4^b	-	-	-	-	-
10	3	2	184.8 ± 1.5^a	-	-	-	-	-
	6	2	143.1 ± 2.0^b	-	-	-	-	-

Data within the same column with different superscript letters are significantly different (*$p < 0.05$*).

Note:

FW - Final weight, CF – Condition factor, WG – Weight gain, SGR – Specific growth weight , FCR – Feed conversion ratio, FE – Feed efficiency, SUR - Survival rate

Source: Field data (2020)

The Recruits

Generally, the weight of recruits recorded in the different treatments were 13.44 ± 1.10 kg, 14.18 ± 3.29 kg, 10.49 ± 0.01 kg and 8.99 ± 0.56 kg for 2 g @ 3/m^2, 2 g @ 6/m^2, 10 g @ 3/m^2 and 10 g @ 6/m^2 respectively as shown in Figure 12. There were no significant differences ($p > 0.05$) within the treatments on the weight recruited during the study.

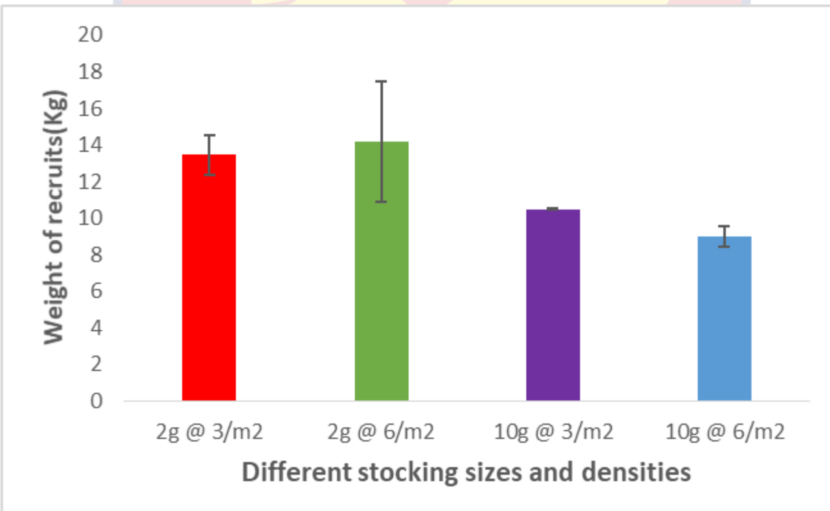

Figure 12: Weight of fish recruits at different stocking sizes and densities during culture of Nile tilapia fingerlings for 154 days in an experimental ponds.

Water Quality Parameters

Temperature

The temperature recorded in the various treatment ponds were within the range required by tilapia for growth as shown in Figure 13A and B. The recorded values were within the following ranges: 2 g @ 3/m^2 (27.6 - 31.3 °C), 2 g @ 6/m^2 (27.6-31.5 °C), 10 g @ 3/m^2 (27.6-31.2 °C) and 10g @ 6/m^2 (27.7-31.4 °C) over the whole period of study. The average temperature for the treatments were 2 g @

3/m^2 29.48 ± 1.41, 2 g @ 6/m^2 29.64 ± 1.39 °C, 10 g @ 3/m^2 29.51 ± 1.36 °C and 10 g @ 6/m^2 29.69 ± 1.40°C as shown in Table 5.

Table 5 - *Water Quality Parameters (Mean ± Standard Deviation) In Experimental Ponds Stocked with Nile Tilapia at Different Densities and Sizes from April To August 2020*

Parameters	Average reading Ranges Treatments			
	2g @ 3/m^2	*2g @ 6/m^2*	*10g @ 3/m^2*	*10g @ 6/m^2*
Temperature (°C)	29.48±1.41a	29.64±0.00a	29.51±1.36a	29.69±1.40a
Ph	6.26±0.14^b	6.23±0.22b	6.38±0.21ab	6.56±0.47a
Dissolve oxygen (mg/l)	3.91±0.82^b	3.9±0.91b	4.70±1.08ab	5.42±2.41a
Turbidity (NTU)	84.89±62.13^a	70.93±50.31a	85.32±49.07a	109.91±75.13a
Total Alkalinity (mg/l)	59.47±7.65^{ab}	49.22±8.22b	61.13±17.54ab	54.72±11.37ab
Ammonia–nitrogen (mg/l)	0.38±0.14a	0.38±0.21a	0.38±0.11a	0.40±0.25a

Treatment means within the same row with different superscript letters are significantly different ($p < 0.05$), n = 2

Source: Field data (2020)

Generally, there was sharp drop in temperature level for all the treatments during the first week after stocking and rose again during the second week (Figure 13 and 14). There was gradually decline in temperature after the second week to the last sampling as shown in Figure 13 and 14.

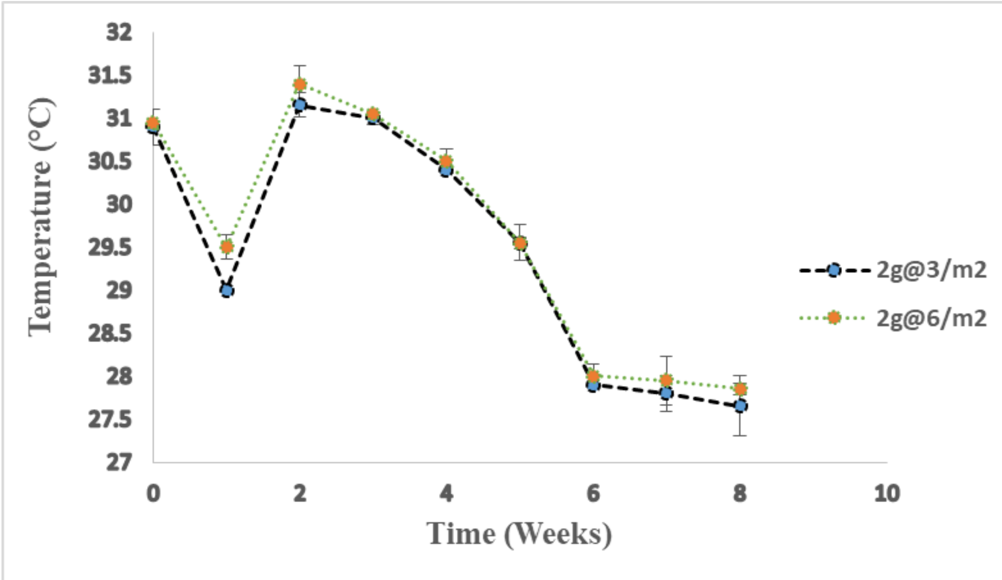

Figure 13: Temperature variations in pond water during culture of Nile Tilapia stocked at 2 g at two different densities (3 fish/m^2 and 6 fish/m^2).

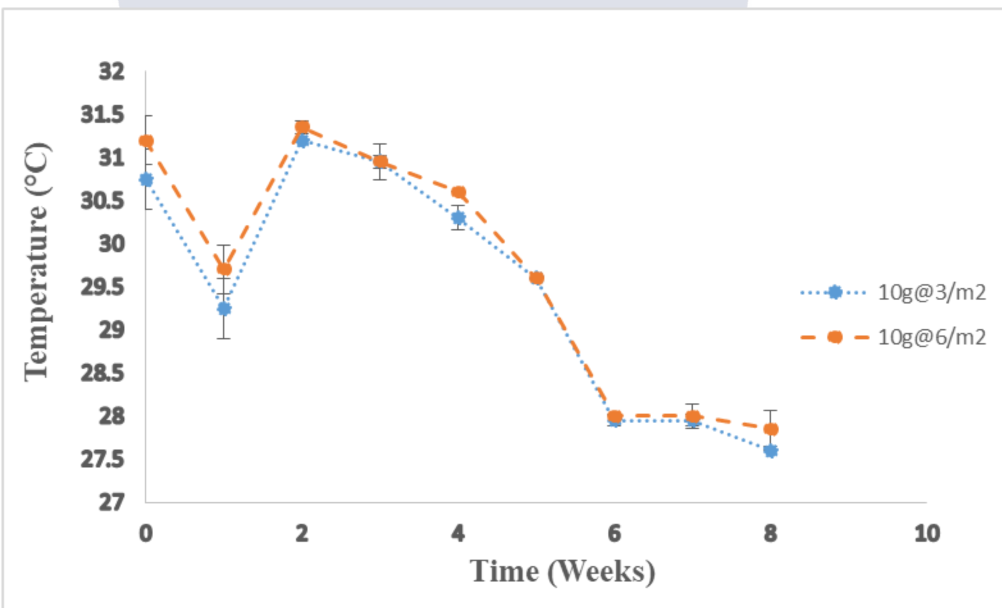

Figure 14: Temperature variations in pond water during culture of Nile Tilapia stocked at 10 g at two different densities (3 fish/m^2 and 6 fish/m^2).

pH

The 10 g @ 3/m^2 treatment recorded the highest pH mean value of 6.27 ± 0.06 whiles the 2 g @ 6/m^2 treatment recorded relatively lowest pH value of 6.24 ± 0.01 (Figure 15). The range of pH values recorded during the study period were 6.08 – 6.56 (2 g @ 3/m^2), 5.84 – 6.64 (2 g @ 6/m^2), 6.06 – 6.78 (10 g @ 3/m^2) and 6.11 – 7.59 (10 g @ 6/m^2). There were significant differences between some of the treatments (*p = 0.0069*) as shown in Table 5.

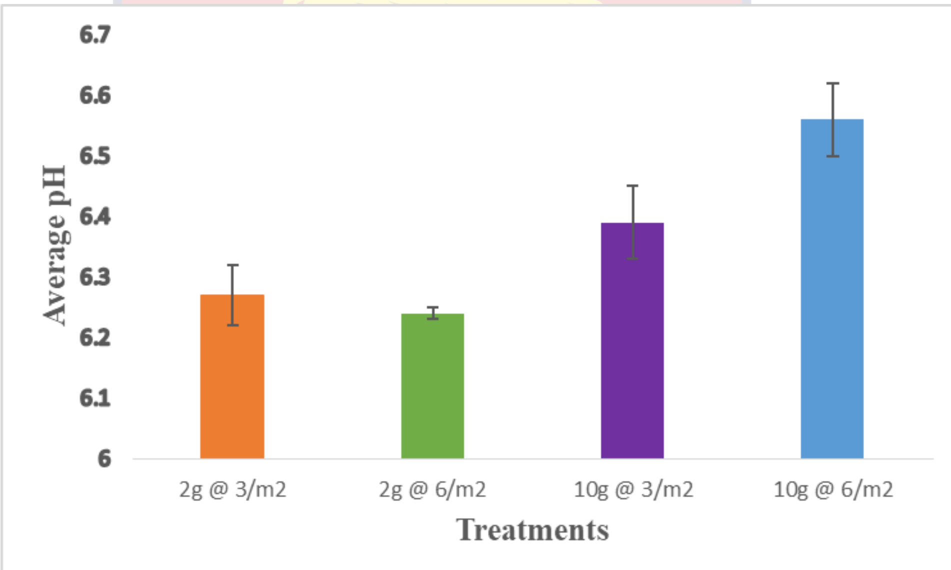

Figure 15: Mean pH of pond water during culture of *O. niloticus* stocked at different sizes and densities.

Dissolve oxygen (DO)

The average DO ranges recorded for 2 g @ 3/m^2 and 2 g @ 6/m^2 treatments were 2.3 – 5.3 mg/l and 2.5 – 5.6 mg/l respectively, whiles that of 10 g @ 3/m^2 and 10 g @ 6/m^2 treatments were 3.1 – 7.3 mg/l and 2.5-10.4 mg/l respectively. The 10 g @ 6/m^2 treatment recorded the highest average DO values of 5.42 ± 2.41 followed by 10 g @ 6/m^2 treatment (4.70 ± 1.08) with 2 g @ 6/m^2 (3.90 ± 0.91) being the least.

Generally, there was sharp decline in DO concentration for 2 g @ 6/m^2 treatment during the sixth sampling week as shown in Figure 16.

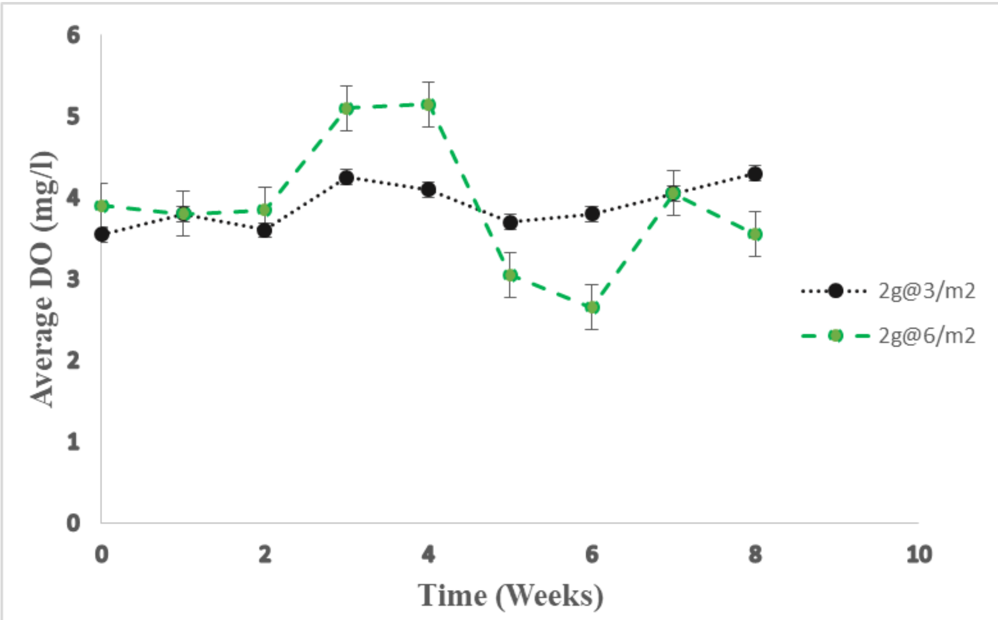

Figure 16: Dissolved oxygen variation in pond water during culture of Nile Tilapia stocked at 2 g at two different densities (3 fish/m^2 and 6 fish/m^2).

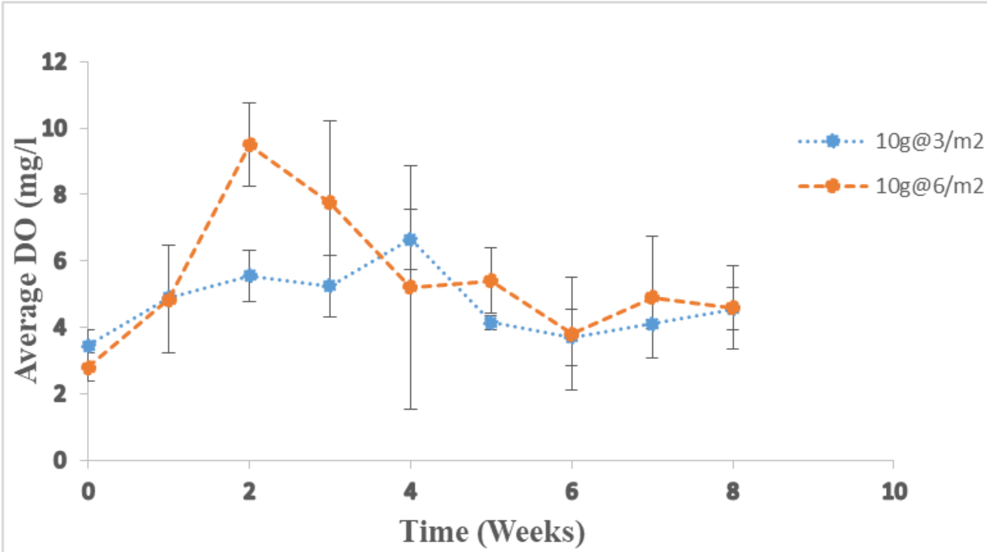

Figure 17: Dissolved oxygen variation in pond water during culture of Nile Tilapia stocked at 10 g at two different densities (3 fish/m^2 and 6 fish/m^2).

Ammonia – nitrogen (NH_3 – N)

The 10 g @ 3/m^2 treatment recorded the highest average value of 0.40 ± 0.25 mg/l whiles the remaining treatments 2 g @ 3/m^2, 2 g @ 6/m^2, and 10 g @ 3/m^2 recorded same average values of 0.38 mg/l with different standard deviations 0.14, 0.11 and 0.21 respectively as shown in Table 5. There was general steady increase in ammonia concentration over time, with alternating high and low values at each respective sampling (Figure 18 and 19). There was no significant diffrences between the various treatment (Table 5).

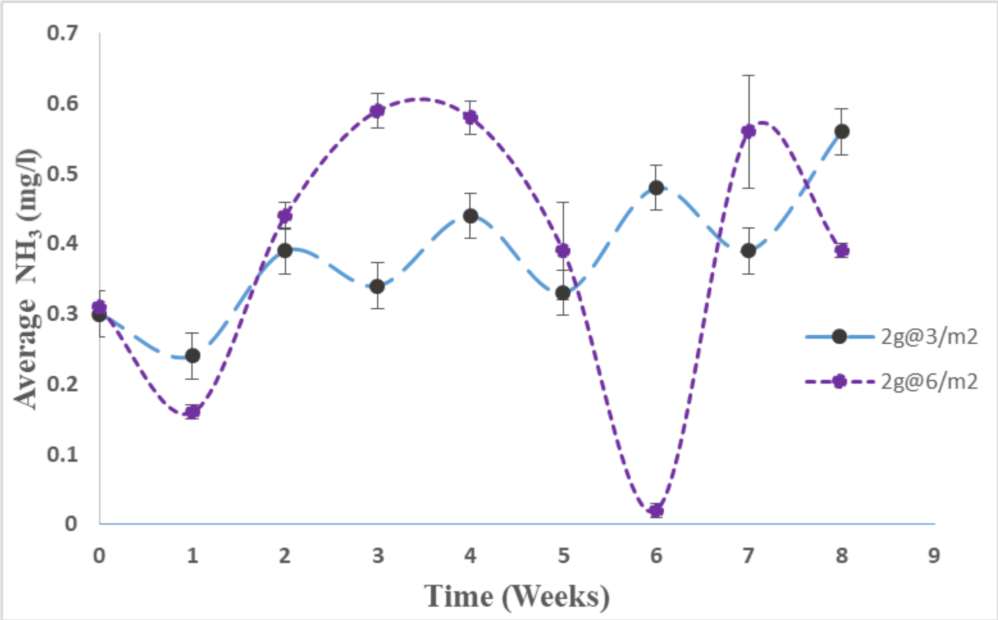

Figure 18: Ammonia – Nitrogen variation in pond water during culture of Nile Tilapia stocked at 2 g at two different densities (3 fish/m^2 and 6 fish/m^2).

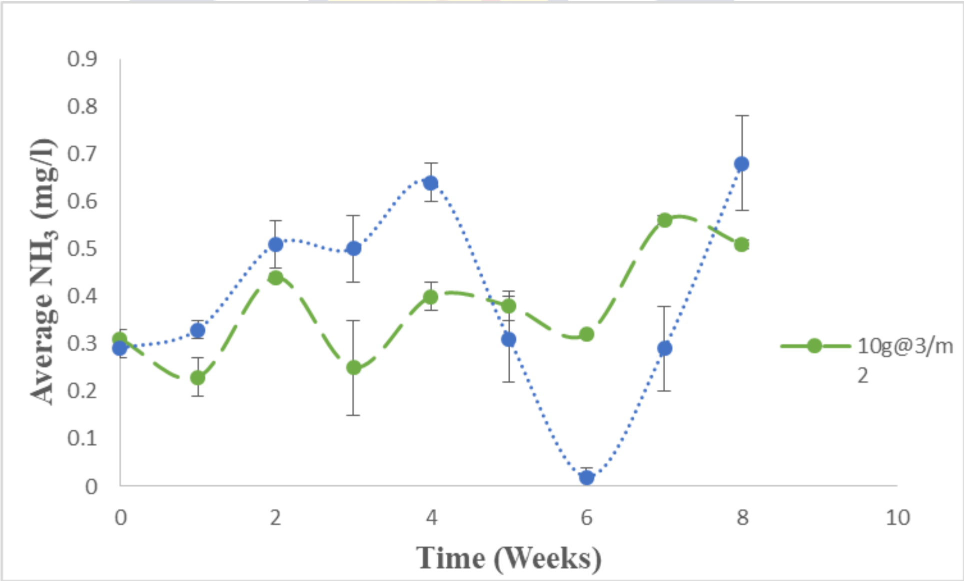

Figure 19: Ammonia-nitrogen variation in pond water during culture of Nile Tilapia stocked at 10 g at two different densities (3 fish/m^2 and 6 fish/m^2).

Total alkalinity

The 10 g @ 3/m^2 treatment recorded the highest average total alkalinity value of 61.13 ± 17.54 mg/l followed by 2 g @ 3/m^2 at 59.47 ± 7.63 mg/l while 2 g @ 6/m^2 treatment recorded the lowest total alkalinity value of 49.22 ± 8.22 mg/l as shown in Table 5. The range of total alkalinity recorded was as follow: 2 g @ 3/m^2 (46.5 – 72mg/l), 2 g @ 6/m^2 (34 – 62 mg/l), 10 g @ 3/m^2 (46 – 79 mg/l) and 10 g @ 6/m^2 (37 – 74 mg/l) over the period of study.

Turbidity

Treatment 10 g @ 6/m^2 recorded the highest average turbidity of value 109.91 ± 75.13 followed by 10 g @ 3/m^2 at 85.32 ± 49.07 whiles treatment 2 g @ 6/m^2 recorded the lowest turbidity value of 70.93 ± 50.31 as shown in Table 5. The 10 g @ 6/m^2 treatment recorded the widest range of 10.8 – 235 NTU while 10 g @ 3/m^2 recorded the lowest range of 31.9 – 163 NTU. The remaining treatments 2 g @ 3/m^2 and 2 g @ 6/m^2 recorded 19.1 – 192 NTU and 10.3 – 152 NTU respectively.

Economic Profitability

The total cost of production, the revenue generated after sale of fish, and the profit or loss incurred as well as return to variable cost were calculated after the study for the various treatments (Table 6). The costs of all basic inputs as well as the prices of fish were based on local market prices at Akosombo as at the study period. The economics of fish production in this study indicated that the total cost of production recorded in the various treatments were higher. The 10 g @ 6/m^2 recorded the highest with an amount of GH¢ 3,213.99 followed by 10 g @ 3/m^2 treatment of GH¢ 2,093.99 with the 2 g @ 3/m^2 having the least cost of production at GH¢ 1,569.99 (Table 6). The cost of feed led to the high cost of production in all the treatments.

Although there was high cost of production in all the treatment, however, profit was made for all the treatments. The 2 g @ 6/m^2 recorded the highest return to variable cost of 50.05 %, followed by the 2 g @ 3/m^2 (38.24 %) with the 10 g @ 6/m^2 having the least (9.46 %) (Table 6).

Table 6 - *Simple Cost and Benefit Analysis of Pond Cultured Nile Tilapia at Different Stocking Densities and Sizes from April to August 2020*

Economic Parameters	Treatments											
	2g @ 3/m2			2g @ 6/m2			10g @ 3/m2			10g @ 6/m2		
	Number	Unit Price (GH¢)	Total (GH¢)	Number	Unit Price (GH¢)	Total (GH¢)	Number	Unit Price (GH¢)	Total (GH¢)	Number	Unit Price (GH¢)	Total (GH¢)
Revenue (GH¢)												
Fish Sales (Kg)	197.30	11.00	2,170.30	281.27	11.00	3,093.97	212.90	11.00	2,341.90	319.83	11	3,518.13
Cost of Production(GH¢)												
Fingerlings (g)	1200	0.15	180.00	2400	0.15	360.00	1200	0.5	600.00	2400	0.5	1,200.00
Feed (Kg)	10	104	1,040.00	13	104.00	1,352.00	11	104	1,144.00	16	104	1,664.00
Lime (Kg)	40	2.00	80.00	40.00	2.00	80.00	40	2	80.00	40	2	80.00
Fuel (liters)	10.48	4.77	49.99	10.48	4.77	49.99	10.48	4.77	49.99	10.48	4.77	49.99
Labour(/week)	22	10	220.00	22	10	220.00	22	10	220.00	22	10	220.00
Total Cost(GH¢)			1,569.99			2,061.99			2,093.99			3,213.99
Net Income(GH¢)		600.31			1,031.98			247.91			304.14	
Return to Variable cost (%)		38.24			50.05			11.84			9.46	

Cost and price information is given in Ghana Cedis (GH₵).

The price of fish at farm gate was GH₵ 11.00 per Kilogram.

Source: Field data (2020)

CHAPTER FIVE

DISCUSSION

Growth Performance of Nile Tilapia

The growth curve showed a gradual growth of fingerlings from the initial stages in all treatments toward the end of experiment (Fig. 10 and 11). Irrespective of size of fish stocked (2 g or 10 g), the final fish weight were significantly higher at $3/m^2$ stocking density compared to $6/m^2$ stocking density for either 2 g or 10 g at stocking. Also, 10 g @ $3/m^2$ did better significantly than 2g @$3/m^2$ treatment. This could be attributed to social interaction through competition for food and space leading to increase energy requirement, which could have contributed to a reduction in growth rate and food utilization by fish stocked at higher density ($6/m^2$) as noted by Mensah *et al*. (2013). There were significant differences between 2 g @ $3/m^2$ and 2 g @ $6/m^2$ with the $3/m^2$ spacing having the highest final weight. This was in line with Yousif (2002), who reported that increasing the number of fish (stocking density) will adversely affect fish growth. Abdel-Hakim, Hilali, Khalil, & Al-Azab (2008), also confirm that lower stocking densities usually result in significantly higher final weight and length in fish.

Generally, the 10 g @ $3/m^2$ recorded the highest average final weight than all other treatments. This agrees with report of Zannatal, Masum, & Ali (2014), which indicated that when the initial weight (stocking size) of fish is high, it influences the body weight during the growth period.

The mean condition factor values recorded for the sizes (2 g and 10 g, were within the range of 2 – 4 as recommended by Bagenal & Tesch (1978) as ideal for Nile tilapia fish. The 6 fish/m^2 stocking density recorded a higher significant mean condition factor value than the 3 fish/m^2 stocking density. This was contrary to statement made by Duodu (2014), that high stocking density has been considered as aquaculture related chronic stressor which causes growth suppression. This could be the cause of variation in water quality and sample size as well as length range. Time of year and stages of maturity may also be a contributing factor.

There was significant difference in mean weight gain between 10g stocking densities and could be attributed to the early spawning that was observed during the fourth week sampling. The present results compare with De Graaf, Galemoni, & Banzoussi, (1996), who observed that in the presence of recruits, growth rate of adult tilapia decreases and fewer marketable-sized fish can be harvested. It could be that they competed for the feed intended for the stocked adult, thereby affecting their weight gain. Similarly, the difference on the 2 g stocking densities may be attributed to the high stocking density which is an inhibitory factor for fish growth due to competition for food and space (Islam, 2002).

The specific growth rate (SGR) in this study was significantly and independently affected by the stocking sizes and densities. The 2 g stocking size, was significantly higher than the 10 g stocking size. This was contrary to what Zannatal *et al.* (2014) and Abdel-Hakim *et al.* (2001) reported on, suggesting that when the initial weight (stocking size) of fish is high it influences the body weight during the growth period, thus resulting in a higher specific growth rate. Similarly, fish stocked at density of 3 fish/m^2 recorded a better mean SGR compared to fish stocked at density of 6 fish/m^2. This was in line with Islam (2002), who reported that lower stocking densities usually lead to higher SGR.

Food conversion ratio seems to have increased with increasing stocking density. That is as stocking densities increased fish became less efficient in utilizing food for somatic growth (Ronald, Bwanika, & Eriku, 2014), because of the competition for food and space. Though there were no significant differences between them, they were both in line with the recommendation made by Bag *et al*., (2016) that, an FCR value that is less than 2.0 is considered "good" in aquaculture industry.

Apparently, all the treatments had appreciable mean feed efficiency values. However higher feed efficiency did not reflect much in their body weight gain. This could be due to the spawning that occurred in all the ponds since most of the energy obtained from the feed was used for the formation of gonads instead of weight gain (Miura *et al*., 2012).

Survival rate of fish is reported in the various ponds were appreciable and this could be the rearing period and the water temperature as stated by Hernandez – Llamas (1996). The 6 fish/m^2 having the least pond survival of fish could be attributed to overcrowding which could have led to competition for space and food. Hence weaker ones could have been eliminated from the population as suggested by Mensah, Attipoe, & Mercy (2013).

Generally, the weight of recruits recorded in the various ponds was high though the ponds were stocked with sex-reversed male *O. niloticus*. This affected the growth of the stocked fish making them stunted confirming what Lovshin, Da Silva, Carneiro-Sobrinho, & Melo (1990) reported that excessive recruitment and subsequent stunting of *O. niloticus* in grow-out ponds is often seen as a major problem in tilapia farming. The massive numbers of fingerlings spawned during the rearing period, utilized part of the feed intended for the stocked adults. Consequently, the growth rate of adult tilapia slowed resulting in reduced harvest yield (De Graaf *et al.*, 1996).

Water Quality Parameters

Generally, temperature recordings in the various treatment ponds were within the optimal range (26 – 30 °C) required by tilapia for growth as stated by Boyd (1990) and Lazur (2007). This was expected because all ponds were exposed to similar environmental conditions such as wind and sunlight (Diana, Lin, & Jaiyen, 1994).

There were wider variations in dissolved oxygen concentrations during the study in all the treatments. This could be as a result of relatively high green algae which usually occurs in wider fluctuations in dissolved oxygen concentration as observed in all the ponds. Diana *et al*. (1994), suggested that wide variation in dissolved oxygen levels could be as a result of the high oxygen demand and nutrient loading at the pond bottom. According to Peterman (2011), the suitable level of dissolved oxygen for Nile tilapia fry and fingerling production should be above 2 mg/l. Generally, all the dissolved oxygen value obtained from the treatments was acceptable for the growth of fry and fingerlings but it appeared lower than the optimum (Boyd, 1990; Makori, Abuom, Kapiyo, Anyona, & Dida, 2017). The earthen ponds used for the study did not have aerators, neither was there regular water exchange for the ponds. Therefore, dissolved oxygen levels could not be enhanced by external provision of aeration or regular water exchange.

Generally, the average pH value for all the treatments as shown in Table 5 were in agreement with Peterman (2011), and Nandlal and Pickering, (2004), whose independent reports indicated that the pH values for optimal growth of Nile tilapia should be within the ranges of 6 and 9. Further studies conducted by Crane (2006) and Makori *et al*. (2017) also stated that pH values should be within the ranges of 6.1 – 8 for survival of Nile tilapia. This suggests that mean water pH values recorded in the various ponds during the study were suitable for Nile tilapia production.

Generally, the 10 g @ $6/m^2$ treatment recorded the highest turbidity mean value while the 2 g @ $6/m^2$ recorded the lowest mean. High level of phytoplankton was observed during the period of culture in most of the ponds especially in the10 g @ $6/m^2$ treatment and this may be the possible cause of the low mean final weight as suggested by James *et al*, (1978), that any increase in turbidity affects light penetration and therefore, can affect primary production, hence oxygen concentration, and temperature. These, in turn, can have sub-lethal effects on fish growth.

Generally, all the average total alkalinity value recorded in the various treatment were below the range recommended by Boyd, Tucker, & Somridhivej (2016) that the total alkalinity for fish culture may range from 75 – 200 mg/l $CaCO_3$. Low level in alkalinity in the ponds could be due to absent of aerators and irregular changing of the water in the ponds. Since total alkalinity within the range of 75 – 200 mg/l $CaCO_3$ contains suitable quantities of carbon dioxide to permit plankton production for fish culture consumption (Boyd *et al.* 2016).

Generally, all the average ammonia – nitrogen mean value recorded in the various treatment were above the recommended range stated by Santhosh and Singh (2007) that the upper limit of ammonia concentration for aquatic organisms may be 0.1 mg/l. Bhatnagar and Singh (2010) and Makori *et al.* (2017), also cited that ammonia levels of < 0.2 mg/l could be suitable for pond culture. This affected the feeding of the fish as observed in the 10g @ $6m^2$ treatment pond during the study.

Economic Production of Nile tilapia Reared at Different Stocking Sizes and Density

The main aim of any aquaculture business is to reduce production cost and maximize profit (Asase, 2013). This would make the farmer know whether to adopt a new production strategy or not. In the present study, feed accounted for more than half of the total cost of production. This confirms Beveridge (2004) finding that feed costs are always the highest variable cost taking almost 50 to 60 % of the total costs of production and the second highest variable cost is fish seed or fingerling costs. The economic analysis shows that all the treatments would be profitable when practiced but the 2 g @ 6/m^2 recorded the highest return to variable cost of 50.05 % followed by 2 g @ 3/m^2 (38.24 %) with the 10 g @ 6/m^2 been the least (9.46 %). This was because the 2 g fingerling cost less than 10g and also stocking at 6/m^2 provided a slightly higher yield which resulted in higher return to variable cost. This confirms the findings of Watanabe, Clark, Dunham, Wicklund, & Olla (1990), who reported that there is a positive relationship between stocking density and production yield for Nile tilapia.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Generally, small-scale aquaculture provides more employment opportunities per unit of capital investment than those with larger farms (Pillay, 1990). The aquaculture sector in Ghana plays a vital role in the national economy by contributing about 3 % to 5 % to the Gross Domestic Product (GDP). It provides employment opportunities to the populace (BOG, 2008). The country current fish production from aquaculture is 52,470.49 metric tonnes a year (MOFAD, 2016). The most important source of animal protein in every part of the country, poor or rich, village or cities comes from fish in Ghana (Anon, 2003).

Production of fingerlings may require a two – stage system where fry from hatcheries is transferred to nursery ponds and then stocked into grow-out ponds to attain a desirable weight such as 10 to 20 g. The regular size of the fingerlings sold by most hatcheries in Ghana is 2.5 g, and because of the high demand, smaller sized fingerlings are often sold, which have lower survival rates (Konyim, 2018). The stocking density and sizes of fish pond have also been found to depend on the culture practices that accommodate single or special combination of fish species for a particular purpose. Lanuza (2000), studied the effect of different stocking sizes on the growth, yield and survival of Nile tilapia in ponds. It was clearly shown that there were no significant differences in stocking sizes ranging from 0.10 to 1.20 g after 90 days of culture. Bigger size fingerlings have also been found to survive better, grow faster, and reach market size sooner (Arce

& Lopez, 1981). This work, therefore, was to assess the suitable stocking size and density that would lead to higher yield with manageable cost of the entire production in a small – scale pond.

The study was carried out at Aquaculture Research and Development Centre (ARDEC) of CSIR-Water Research Institute (CSIR-WRI), Ghana at Akosombo in Eastern Region of Ghana with eight experimental ponds, each of size 200 m^2. The ponds were cleared and allowed to dry and was lime prior to filling with water from the Volta Lake.

Sex-reversed male *O. niloticus* of the Eleventh generation of "Akosombo Strain" developed by CSIR-WRI at ARDEC, Akosombo through selective breeding were conditioned for three days before transferring into the experimental ponds. Two different sizes (2 g and 10 g) of Nile Tilapia were replicated at two different stocking densities 3 fingerlings per square meter and 6 fingerlings per square meter.

Fish were fed with commercial diet of forty (40 %) crude protein at an initial rate of 8 % body weight (BW) to T_1 and T_2. Whiles T_3 and T_4 were given 6% body weight (BW) of the same feed. Feeding was done three times daily by hand broadcast at four hours interval. The feed was adjusted as the fishes were increasing in sizes.

At least fifty (50) individual fishes were sampled randomly every two weeks using drag net. Their standard length, total length and weight were taken using measuring board and digital scale respectively from each pond. Fish growth performance was determined in terms of survival per pond, Mean weight gain (MWG), specific growth rate (SGR), feed conversion ratio (FCR) and feed efficiency (FE).

Water quality parameters such as temperature, dissolve oxygen (DO), nitrite (NO_2), ammonia (NH_3), hydrogen ion concentration (pH), and total alkalinity of ponds were monitored prior to stocking and bi-weekly thereafter. All water analyses were done at ARDEC Lab at Akosombo with the exception of temperature that was taken in situ. The samples were taken between 9:00 am to 9:30 am in the morning.

The result of the present study showed that the mean final weight recorded were 195.0 ± 18.5 g, 181.7 ± 16.3 g, 153.3 ± 27.5 g and 152.2 ± 18.8 g, for 10 g @ $3/m^2$, 2 g @ $3/m^2$, 10 g @ $6/m^2$ and 2 g @ $6/m^2$ respectively. Feed conversion ratio and Feed efficiency for all the treatments were not significantly different. Temperature, pH and alkalinity were all within optimal range required by tilapia for growth while the average dissolved oxygen was below the optimal range required for tilapia growth. Turbidity and ammonia – nitrogen values were also above the optimal range require for tilapia growth. The 2 g @ $6/m^2$ recorded the highest return to variable cost of 50.05 % follow by 2 g @ $6/m^2$ (38.24 %) with the 10 g @ $3/m^2$ been the least.

Conclusions

The growth parameters monitored in both stocking size and density independently had significant impact on fish final weight, condition factor, weight gain, specific growth rate and fish survival at different probability levels. Final mean weights of fish among treatments were significantly different (*$p < 0.05$*) except for T_2 and T_4. Survival of fish was relatively higher for both high stocking size of 10 g (87.5 %) and lower stocking density of 3 fish/m^2 (90.0 %).

Generally, the water quality parameters (Temperature, pH and Alkalinity) were all within the optimal range required by tilapia for growth however, the dissolved oxygen values recorded appeared to be below optimal range required for tilapia growth. Turbidity and average ammonia – nitrogen were also above optimal range require by tilapia for growth and this could be attributed to irregular change of water in the ponds and absence of aerators in the pond during the culture.

This implies that under the present conditions, small-scale operations are economically viable of which potential farmers can venture. It could be suggested to small – scale pond farmers to rear tilapia of 10 g stocking size at 3 fish/m^2 stocking density to get higher growth, survival and benefit in a short period of time**.** However, farmers could also rear 2 g at 6/m^2 because stocking at 6/m^2 provided a slightly higher yield.

Recommendation

1. Fish farmers are to rear bigger size Nile tilapia fingerlings, preferably sizes above 10 g, and maintain stocking density at 3/m^2 in other to realize high yield, survival and economics returns.

2. This study has provided pond management guidelines which could be adapted by small – scale fish farmers for efficient aquaculture production in Ghana.
3. More work needs to be done on hormonal feed to achieve 100% mono-sex male tilapia for small - scale pond production in Ghana.
4. There should be regular water exchange and use of aerators for pond culture.

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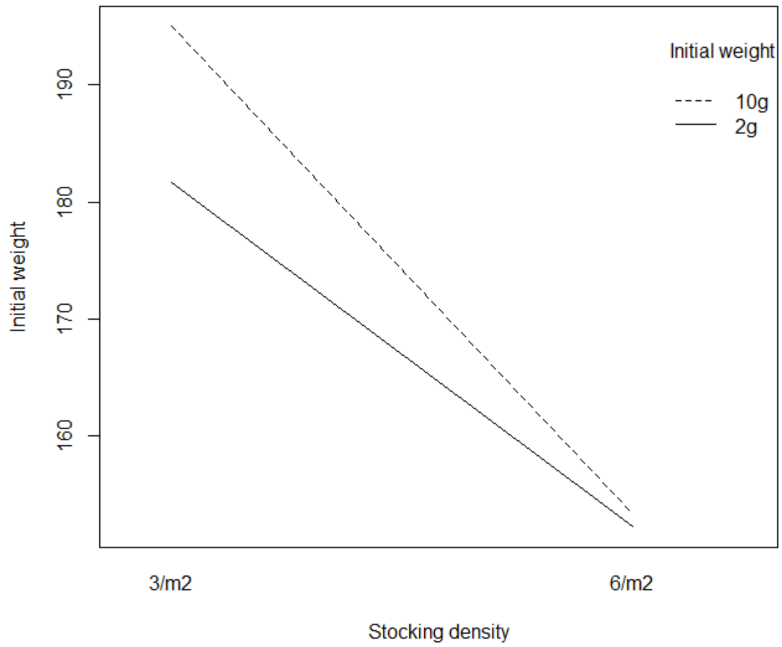
APPENDICES

Appendix 1 - *Final weight*

```
Anova Table (Type III tests)

Response: fbw
              Sum Sq  Df   F value    Pr(>F)
(Intercept) 3801915   1 8856.7529 < 2.2e-16 ***
iw             8891   1   20.7123  7.11e-06 ***
den           86974   1  202.6096 < 2.2e-16 ***
iw:den         3762   1    8.7637  0.003258 **
Residuals    169990 396
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1
```

```
$statistics
   MSerror  Df     Mean       CV      MSD
  429.2674 396 170.5308 12.14958 7.559517

$parameters
   test name.t ntr StudentizedRange alpha
  Tukey  iwden   4         3.648632  0.05

$means
              fbw      std   r   Min   Max     Q25    Q50
Q75
10g.3/m2 194.985 18.46338 100 141.5 265.5 183.000 193.25
204.250
10g.6/m2 153.278 27.48633 100 102.5 207.0 130.125 149.00
170.125
2g.3/m2  181.650 16.33357 100 145.0 226.0 171.500 181.25
190.500
2g.6/m2  152.210 18.81196 100 102.5 196.5 141.500 151.50
163.000

$comparison
NULL

$groups
              fbw groups
10g.3/m2 194.985      a
2g.3/m2  181.650      b
10g.6/m2 153.278      c
2g.6/m2  152.210      c
```

Appendix 2 - *Interaction Plot of Stocking Weight and Density for Final Weight*



Appendix 3 - *Condition Factor (CF)*

```
> Anova(mod.fk, type='III')
Anova Table (Type III tests)

Response: fk2
            Sum Sq  Df    F value    Pr(>F)
(Intercept) 550.67   1 11483.7081 < 2.2e-16 ***
iw            0.23   1     4.7052  0.030665 *
den           0.70   1    14.5399  0.000159 ***
Residuals    19.04 397
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1
```

```
$statistics
     MSerror  Df     Mean        CV         MSD
  0.04795246 397 2.05025 10.68067 0.04305063

$parameters
   test name.t ntr StudentizedRange alpha
  Tukey     iw   2         2.780284  0.05

$means
       fk2       std   r Min Max Q25 Q50 Q75
10g 2.0740 0.2484606 200 1.4 3.1 1.9   2 2.2
2g  2.0265 0.1934811 200 1.7 2.9 1.9   2 2.1

$groups
       fk2 groups
10g 2.0740      a
2g  2.0265      b
```

```
$statistics
     MSerror  Df     Mean        CV         MSD
  0.04795246 397 2.05025 10.68067 0.04305063

$parameters
   test name.t ntr StudentizedRange alpha
  Tukey    den   2         2.780284  0.05

$means
        fk2       std   r Min Max Q25 Q50 Q75
3/m2 2.0085 0.1864176 200 1.7 3.1 1.9   2 2.1
6/m2 2.0920 0.2490908 200 1.4 2.9 1.9   2 2.2

$groups
        fk2 groups
6/m2 2.0920      a
3/m2 2.0085      b
```

Appendix 4 - *Weight Gain*

```
> Anova(mod.WG, type='III')
Anova Table (Type III tests)

Response: WG
            Sum Sq Df   F value    Pr(>F)
(Intercept)  63921  1 24768.382 9.778e-09 ***
iw              37  1    14.230  0.019566 *
den            866  1   335.610 5.223e-05 ***
iw:den          76  1    29.311  0.005639 **
Residuals       10  4
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1
```

```
$statistics
  MSerror Df    Mean        CV      MSD
  2.58075  4 164.015 0.9794661 6.539712

$parameters
   test name.t ntr StudentizedRange alpha
  Tukey  iwden   4         5.757058  0.05

$means
          WG      std r    Min    Max      Q25     Q50
Q75
10.3 184.835 1.548564 2 183.74 185.93 184.2875 184.835
185.3825
10.6 143.105 1.958686 2 141.72 144.49 142.4125 143.105
143.7975
2.3  178.775 1.491995 2 177.72 179.83 178.2475 178.775
179.3025
2.6  149.345 1.364716 2 148.38 150.31 148.8625 149.345
149.8275

$groups
          WG groups
10.3 184.835      a
2.3  178.775      a
2.6  149.345      b
10.6 143.105      b
```

Appendix 5 - *Specific Growth Rate*

```
> Anova(mod.SGR, type='III')
Anova Table (Type III tests)

Response: SGR
             Sum Sq Df    F value    Pr(>F)    
(Intercept) 14.4722  1 44529.8462 3.025e-09 ***
iw           0.5929  1  1824.3077 1.796e-06 ***
den          0.0110  1    33.9231  0.004328 ** 
iw:den       0.0013  1     3.8462  0.121393    
Residuals    0.0013  4                         
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '
' 1

> Anova(mod.SGR2, type='III')
Anova Table (Type III tests)

Response: SGR
             Sum Sq Df   F value    Pr(>F)    
(Intercept) 19.4760  1 38188.268 6.658e-11 ***
iw           1.2640  1  2478.529 6.179e-08 ***
den          0.0338  1    66.275 0.0004541 ***
Residuals    0.0026  5                        
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '
' 1
```

```
$statistics
  MSerror Df Mean       CV       MSD
  0.00051  5 2.24 1.008178 0.0410489

$parameters
   test name.t ntr StudentizedRange alpha
  Tukey     iw   2         3.635351  0.05

$means
      SGR        std r  Min  Max    Q25   Q50   Q75
10 1.8425 0.09069179 4 1.75 1.93 1.7725 1.845 1.915
2  2.6375 0.06238322 4 2.57 2.70 2.5925 2.640 2.685

$groups
      SGR groups
2  2.6375      a
```

```
10 1.8425      b

> b<-HSD.test(mod.SGR2, 'den', group=T)
> b
$statistics
  MSerror Df Mean       CV       MSD
  0.00051  5 2.24 1.008178 0.0410489

$parameters
   test name.t ntr StudentizedRange alpha
  Tukey    den   2         3.635351  0.05

$means
    SGR       std r  Min Max    Q25   Q50    Q75
3 2.305 0.4447096 4 1.91 2.7 1.9250 2.305 2.6850
6 2.175 0.4737440 4 1.75 2.6 1.7725 2.175 2.5775

$groups
    SGR groups
3 2.305      a
6 2.175      b
```

Appendix 6 - *Feed Conversion Ratio*

```
> Anova(mod.FCR, type='III')
Anova Table (Type III tests)

Response: FCR
             Sum Sq Df  F value    Pr(>F)
(Intercept) 3.02580  1 461.0743 2.782e-05 ***
iw          0.00640  1   0.9752    0.3793
den         0.01210  1   1.8438    0.2461
iw:den      0.00001  1   0.0019    0.9673
Residuals   0.02625  4
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1
> mod.FCR2 <- lm(FCR ~ iw+den, data=df)
> Anova(mod.FCR2, type='III')
Anova Table (Type III tests)

Response: FCR
            Sum Sq Df  F value    Pr(>F)
(Intercept) 4.0262  1 766.5310 1.151e-06 ***
iw          0.0136  1   2.5916   0.16834
den         0.0231  1   4.4003   0.09002 .
```

```
Residuals   0.0263  5
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1
```

Appendix 7 - *Feed Efficiency*

```
> Anova(mod.FE, type='III')
Anova Table (Type III tests)

Response: FE
             Sum Sq Df  F value    Pr(>F)
(Intercept) 13247.0  1 401.9488 3.653e-05 ***
iw             23.3  1   0.7079    0.4475
den            69.8  1   2.1181    0.2193
iw:den          1.8  1   0.0553    0.8256
Residuals     131.8  4
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1
> mod.FE2 <- lm(FE ~ iw+den, data=df)
> Anova(mod.FE2, type='III')
Anova Table (Type III tests)

Response: FE
             Sum Sq Df  F value    Pr(>F)
(Intercept) 17870.6  1 668.5483 1.616e-06 ***
iw             66.9  1   2.5040   0.17441
den           109.5  1   4.0972   0.09885 .
Residuals     133.7  5
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
' ' 1
```

Appendix 8 - *Pond Survival (SUR), Logistic Regression Model*

```
Single term deletions

Model:
y ~ iw + den
       Df Deviance    AIC F value  Pr(>F)
<none>      3.4546 71.929
iw      1   9.4184 75.893  8.6318 0.03233 *
den     1  10.5570 77.032 10.2797 0.02383 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
```

```
` ' 1

Call:
glm(formula = y ~ iw + den, family = binomial(), data =
df)

Deviance Residuals:
      1         2         3         4         5         6
7        8
 0.9168   0.2533  -0.8919  -0.2778  -0.1861  -0.6784  -
0.2344   1.0617

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.14485    0.03443  -4.207 2.59e-05 ***
iw10         0.08504    0.03483   2.442  0.01462 *
den6        -0.09763    0.03663  -2.666  0.00768 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
` ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 16.3731  on 7  degrees of freedom
Residual deviance:  3.4546  on 5  degrees of freedom
AIC: 71.929

Number of Fisher Scoring iterations: 3
```

Appendix 9 - *Pond Survival (SUR), Linear Model, Arcsine-transformed*

```
Anova Table (Type III tests)

Response: asinsur
            Sum Sq Df  F value    Pr(>F)
(Intercept) 5.0918  1 693.8386 1.976e-07 ***
den         0.0518  1   7.0643   0.03763 *
Residuals   0.0440  6
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
` ' 1
```

Appendix 10 – *Temperature Readings of Pond Water during the Culture of Nile tilapia*

	Temperature (°C)							
	2 g @ 3/m²		10 g @ 3/m²		2g @ 6/m²		10 g @ 6/m²	
WEEKS	SP1	SP3	SP2	SP4	SP5	SP7	SP6	SP8
0	30.9	30.9	30.5	31	30.8	31.1	31	31.4
1	28.9	29.1	29	29.5	29.5	29.5	29.5	29.9
2	31	31.3	31.2	31.2	31.3	31.5	31.3	31.4
3	31	31	30.9	31	31	31.1	31.1	30.8
4	30.3	30.5	30.2	30.4	30.5	30.5	30.6	30.6
5	29.4	29.7	29.6	29.6	29.5	29.6	29.6	29.6
6	27.8	28	27.9	28	28	28	28	28
7	27.6	28	27.9	28	27.8	28.1	28.1	27.9
8	27.6	27.7	27.6	27.6	27.6	28.1	28	27.7
Average	29.39	29.58	29.42	29.59	29.56	29.72	29.69	29.70

Appendix 11 – *Dissolve Oxygen Readings of Pond Water during the Culture of Nile tilapia*

	Dissolve Oxygen (mg/l)							
	2 g @ 3/m²		10 g@ 3/m²		2 g @ 6/m²		10 g @ 6/m²	
WEEKS	SP1	SP3	SP2	SP4	SP5	SP7	SP6	SP8
0	3.9	3.2	3.1	3.8	3.4	4.4	2.5	3.1
1	4.1	3.5	4.9	4.9	3.6	4	3.7	6
2	4.4	2.8	6.1	5	4.4	3.3	10.4	8.6
3	3.5	5	5.9	4.6	5.2	5	9.5	6
5	4.5	3.7	7.3	6	5.6	4.7	2.6	7.8
6	2.9	4.5	4.3	4	3.3	2.8	6.1	4.7
7	2.3	5.3	3.1	4.3	2.8	2.5	2.6	5
8	3.3	4.8	4.2	4	3.7	4.4	3.6	6.2
9	4.2	4.4	5	4.1	2.8	4.3	5.5	3.7
Average	3.68	4.13	4.88	4.52	3.87	3.93	5.17	5.68

Appendix 12 – *Ammonia - nitrogen Readings of Pond Water during the Culture of Nile tilapia*

	Ammonia - Nitrogen (mg/l)							
	2 g @ 3/m^2		10 g @ 3/m^2		2 g @ 6/m^2		10 g @ 6/m^2	
WEEKS	SP1	SP3	SP2	SP4	SP5	SP7	SP6	SP8
0	0.336	0.255	0.326	0.298	0.307	0.303	0.298	0.274
1	0.383	0.095	0.199	0.251	0.17	0.147	0.35	0.317
2	0.341	0.445	0.43	0.449	0.464	0.435	0.544	0.468
3	0.298	0.383	0.18	0.326	0.766	0.407	0.449	0.553
5	0.378	0.501	0.374	0.416	0.747	0.412	0.828	0.454
6	0.218	0.435	0.36	0.397	0.331	0.426	0.478	0.147
7	0.634	0.317	0.322	0.322	0.024	0.014	0.033	0.009
8	0.27	0.506	0.563	0.549	0.506	0.615	0.52	0.066
9	0.421	0.695	0.501	0.516	0.383	0.397	0.445	0.918
Average	0.364	0.404	0.362	0.392	0.411	0.351	0.438	0.356

Appendix 13 – *Turbidity Readings of pond Water during the Culture of Nile tilapia*

	Turbidity (NTU)							
	2 g @ 3/m^2		10 g @ 3/m^2		2 g @ 6/m^2		10 g @ 6/m^2	
WEEKS	SP1	SP3	SP2	SP4	SP5	SP7	SP6	SP8
0	19.1	11.8	31.9	16.7	10.3	14.5	11.5	10.8
1	27	18.1	24.5	23.8	11.4	18.5	18.6	18.2
2	36.7	37.9	41.8	35.8	21.8	28.1	36.3	34.6
3	87.5	30.4	103	131	32.3	38.6	167	120
5	93.8	21.3	96.6	40.8	109	41.9	42.3	124
6	174	97.6	149	97.3	152	118	151	163
7	87.8	136	113	134	91.7	122	165	161
8	192	167	133	122	131	116	154	215
9	132	158	163	78.6	97.7	122	151	235
Average	94.43	75.34	95.09	75.56	73.02	68.84	99.63	120.18

Appendix 14 – *pH Readings of Pond Water during the Culture of Nile tilapia*

	pH							
	2 g @ 3/m^2		10 g @ 3/m^2		2 g @ 6/m^2		10 g @ 6/m^2	
WEEKS	SP1	SP3	SP2	SP4	SP5	SP7	SP6	SP8
0	6.13	6.12	6.1	6.35	6.08	6.13	6.18	6.15
1	6.15	6.32	6.36	6.65	6.31	6.4	6.45	6.56
2	6.56	6.34	6.68	6.78	6.45	6.43	7.59	7.45
3	6.51	6.36	6.43	6.64	6.52	6.61	7.23	6.76
4	6.38	6.13	6.52	6.53	6.64	6.24	6.16	7.08
5	6.29	6.2	6.21	6.26	6.01	6.08	6.25	6.22
6	6.18	6.38	6.22	6.36	6.13	6.27	6.3	6.66
7	6.25	6.11	6.27	6.26	6.13	6.15	6.3	6.37
8	6.21	6.08	6.24	6.06	5.84	6.03	6.2	6.11
Average	6.30	6.23	6.34	6.43	6.23	6.26	6.52	6.60

Appendix 15 – *Total Alkalinity Readings of Pond Water during the Culture of Nile tilapia*

	Total Alkalinity (mg/l)							
	2 g @ 3/m^2		10 g @ 6/m^2		2 g @ 6/m^2		10 g @ 6/m^2	
WEEKS	SP1	SP3	SP2	SP4	SP5	SP7	SP6	SP8
0	62	61	72	68	53	59	51.5	50
1	68	72	75.5	79	62	60	74	59
2	68	68	76	77	54	58	70.5	59
3	67	67.5	73	78.5	57	55	70	53.5
5	50	52.5	54	5.75	42	44	58	39
6	57	57	59.5	61.5	46	46.5	63	44.5
7	57	57	59	55	43.5	45.5	63	42
8	46.5	55	58.5	48	37	44.5	59	38
9	48	57	54	46	34	45	54	37
Average	58.17	60.78	64.61	57.64	47.61	50.83	62.56	46.89