GROWTH PERFORMANCE OF TILAPIA IN DIFFERENT CULTURE SYSTEMS ON VARYING INPUT AMOUNTS AND AQUACULTURE TECHNOLOGIES ADOPTION IN MERU COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for any Award or a Degree in any other University.

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To my special family Julia Mbaabu, Prudence Gatwiri Mbaabu, Vincent Kimathi Mbaabu and my late father, Bruno Kinoti Mutea for his sacrifice and struggle to educate every sibling in the family.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
BMP	Best Management Practices
CP	Crude Protein
CIDP	County Integrated Development Plan
ESP	Economic Stimulus Project
FAO	Food and Agricultural Organization
FCR	Feed Conversion Ratio
GAqP	Good Aquaculture Practices
HSD	Highest Significant Difference
ICM – FFS	Integrated Crop Management Farmer Field School
IPM	Integrated Pest Management
KWS	Kenya Wildlife Service
NEMA	National Environment Management Authority
WARM	Water Association Resources Management

ABSTRACT

Prior to 2010 aquaculture production in Kenya was low, 4895 MT annually and adoption. Information on effects of various inputs on growth performance of tilapia, the best culture system and aquaculture adoption in Meru County is scanty or missing. The purpose of this study was therefore to find out the effects of varying the amounts of fish feed pellets, fertilization and liming pond water under different physicochemical parameters on the performance of *Oreochromis niloticus* in different culture systems (ponds) in Meru County, Kenya over a period of three months, August 2015 to November 2015. The study also investigated determinants of adoption of fish farming technologies (liner, concrete and earthen culture) in the study area. Fourty Eight (48) fish ponds of size 2m x 1m x1m deep of each type were constructed in a randomized block design in the study area. Each pond was stocked with 8 *Oreochromis niloticus* monosex fingerlings each of approximately 20gm. Fish were fed daily at 10 am and 4 pm. Growth performance of the fish was measured after 30, 60 and 90 days under different treatments. The parameters which were measured were, weight gain of the fish, total production from the various ponds and adoption level of fish farming technologies. ANOVA was used to determine if there was any significant difference in the mean weight gain of the fish in the three culture systems under different treatments. On adoption, a questionnaire was used to collect information on the factors which influence adoption of fish farming technologies. Ninety (90) fish farmers and Ninety (90) non – fish farmers were interviewed through a structured questionnaire to determine the factors and level of adoption. Logit regression analysis was used to analyze primary data on adoption collected from the field. Results revealed that varying amounts of fish feed pellets (2, 4, and 6 gms) had no significant difference in the weight gain of fish in the three culture system. When pond water was fertilized at different fertilization rates, concrete culture system produced highest mean weight gain of 11.21 ± 3.27 gms, earthen 7.67 ± 1.36 gms and liner 6.41 ± 4.88 gms with 4 gms DAP showing a significance difference in mean weight gain ($F = 20.07$, $df = 2$, $P = 0.002$). Liming the pond water produced almost a similar trend with fish in concrete pond recording a mean fish weight gain of 8.87 ± 3.75 gms, liner 7.20 ± 1.89 gms and earthen 7.12 ± 1.91 gms with 4 gms lime showing a significance difference ($F = 5.18$, $df = 2$, $P = 0.049$). On combining all the inputs at various levels of (pellets, fertilizer and lime), there was no significant difference in mean weight gain of fish in the culture systems. Concrete culture system recorded the highest mean weight gain of 9.44 ± 2.05 gms and liner 7.35 ± 3.70 gms. On determinants of adoption, the study showed that, out of the eleven factors assessed, market access, extension services, credit access and annual farm income significantly ($p<0.05$) influences the adoption of fish farming technologies (liner, concrete and earthen) in Meru County. The study concluded that the use of different levels of aquaculture inputs affects the growth performance of *Oreochromis niloticus* in different culture systems. Planners and Fisheries managers of aquaculture projects and programmes are encouraged to prioritize market access, extension services, credit access and annual farm income in their administration and implementation of all fisheries projects for higher success rate leading to improved fish production and livelihoods of fish farmers. Policy makers to create provision in law for market access, extension services, credit access, farm income streams and linkages strengthening inorder to transform the aquaculture sector.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Globally, fish provides more than one billion people with high quality daily animal protein (Bush, *et al.*, 2019). More than 250 million people globally depend directly on fisheries and aquaculture for their livelihoods and millions are employed in the sector in roles such as processing or marketing. Fish is the primary source of nutrition being an affordable animal source of protein in some of the poorest countries, creating growing demand for this staple. However, fish supplies are failing to meet demand and there are major shortages in some developing countries where they are needed most (Rimm, 2015, Bush, *et al.*, 2019)

Fish controls diseases, is a source of income and employment (Jose, 2018). Fish is an important source of essential nutrients and micro - nutrients, omega - 3s fatty acids, cognitive to physical and mental health development in human beings (Jeniffer, 2018: Rimm, 2015). According to (Shutter, 2018), fish consumption is associated with a lower risk of fatal and coronary heart diseases, reduces risk of Alzheimer's brain disease, decreases symptoms of depression, improves quality of brain , vision and eye health among others . Fish is usually high in unsaturated fats, rich in vitamin D and provides health benefits in protection against cardiovascular diseases (Shutter, 2018). In addition fish is very rich in iodine and selenium minerals which are very essential for proper functioning of thyroid gland and thyroid hormone biosynthesis and metabolism. The two minerals are at times difficult to obtain in sufficient quantities from other foods (National Centre for Biotechnology Information, U.S. National Library of Medicine). Additionally, fish has more than twelve by - products which among them include leather, fish oil, fish meal, fish manure, fish glue, isinglass, gunny powder and surgical threads among others (Masifundise, 2014). Larvivorous fish, Panchax, Gambusia, Trichogaster and Haplochitus which consume mosquito larva, assist in controlling diseases in the environment like yellow fever, malaria and other dangerous diseases that are spread by mosquitoes (Jose, 2018).

The amount of fish being captured in the wild globally leveled out from the 1990s and the State of World Fisheries and Aquaculture reports that 90.9 million tonnes of fish was captured globally in the wild in 2016 — a reduction of 2 million tonnes from the year before. In Africa, aquaculture production has stagnated at about 430,000 tonnes same period (Helga, 2010)

Oreochromis niloticus has for many decades been responsible for the global tilapia production from freshwater aquaculture and it accounts for about 83 % of total tilapia produced worldwide (Jose, 2018). It is the most preferred strain of tilapia due to its high feed conversion ratio (FCR), superior taste, big size for filleting, high demand and therefore is the widely grown farmed fish (Hooley *et al.*, 2014), compared to other species. However, aquaculture's growth has slowed leveling out to 5.8 percent annual growth between 2010 and 2016, down from 10 percent in the 1980s and 1990s (Jose, 2018). Thus there is need to promote fish farming to fill the production gaps. Aquaculture growth is measured by collecting all fish harvest data from various fish farms annually.

Despite the government of Kenya promoting aquaculture (fish farming) especially from 2009 to 2013 through the introduction of the famous Economic Stimulus Fish Farming Enterprise Programme, fish production still remains low in the country (Opiyo *et al.,* 2014). Prior to 2010 aquaculture production in Kenya was low, 4895 MT annually

(KNBS, 2017). Through the famous Fish Farming Economic Stimulus programme of 2009 – 2013, Kenyan government attempted to revamp the fisheries sector but production still remains low, 14,952 MT (KNBS, 2017).

Fish catch from Lake Victoria has been declining over time due to overfishing, unsustainable management practices, water hyacinth invasion, industrial and agricultural pollution (Jose, 2018). In Lake Victoria, annual fish catch landed in 2006 was 143,900 tonnes declining to less than 108,000 tonnes in 2016 and the decline has been going on over time (Jose, 2018). Kenyan Indian Ocean fisheries is underexploited landing less than 9,000 tonnes annually (FAO, 2013). The very poor often rely on fishing as a primary source of income. These small-scale fishers are particularly vulnerable as fish stocks diminish. Increased productivity from sustainable aquaculture can be a driver for rural development by mitigating risks to livelihoods and contributing to income generation and employment. Demand for fish and fisheries products has been increasing with increase in population, hence the government's effort to increase fish production through aquaculture (Opiyo *et al.*, 2014).

A sustainable approach to aquaculture will help to protect our natural resources and ensure that fish stocks are available for future generations. Currently aquaculture, in particular, has tremendous potential to enhance food security and be environmentally sustainable. Small-scale aquaculture is especially important for meeting the world's growing demand for fish. As fish farming require a smaller environmental footprint than other animal based enterprises, aquaculture is a more environmentally sustainable option for meeting the world's food needs than other animal source foods (Jose, 2018). According to Gitonga *et al*., (2017), in Kenya tilapia farming was promoted as a family subsistence activity but this did not create sufficient incentives for fish farmers to commercialize their aquaculture activities. Tilapia farming in Kenya ranges from a rural subsistence, extensive, low input practice, non-commercial and household consumption to largely limited semi- commercial production (IFAD, 2017). The reason therefore I conducted the study was to contribute to solutions geared towards addressing the low aquaculture adoption and production. Information on effects of various inputs; commercial fish pellets, Diammonium phosphate and lime in different culture systems is limited or completely absent. The study therefore sought to address the gaps in low tilapia production and adoption in Meru County, Kenya.

1.2 Statement of the problem

In Meru County aquaculture production is still low, only 162 tonnes of fish annually even with the introduction of Economic Stimulus Programme. Adoption of aquaculture technologies is also low in the county. Information on the effect of varying commercial fish pellet amounts, inorganic fertilizer and liming of ponds on growth performance of *Oreochromis niloticus* and the best culture system is missing or scanty. Information on when to harvest the fish from different culture systems and aquaculture adoption is also lacking. Factors limiting adoption of aquaculture not well known. Therefore the study aimed to determine growth performance of *Oreochromis niloticus* in different culture systems using varied fish pellets amounts, inorganic fertilizer, lime and a combination of the inputs. The study also investigated the factors influencing adoption of aquaculture technologies in the county. The results obtained are important in recommendation of improved ways of fish rearing and the more appropriate and effective culture systems to boost fish production in order to enhance food security, wealth and nutritional requirements of the county's residents.

1.3 Broad objective

To assess the growth performance of Nile tilapia (*Oreochromis niloticus*) in different culture systems on varying amounts of inputs and factors influencing the adoption of aquaculture in Meru County**.**

1.3.1 Specific objectives

1. To determine the effects of water physico-chemical parameters on growth performance of *Oreochromis niloticus* in the various culture systems.
2. To find out the effect of varying fish pellets amounts, pond water fertilization and liming rates on the growth performance of *Oreochromis niloticus* in different culture systems.
3. To determine the effect of combined fish pellets, fertilizer and lime on growth performance of *Oreochromis niloticus* in different culture systems.
4. To assess the level of adoption of aquaculture technologies and the factors that influence adoption in the study area.

1.4 Research questions

The research questions the study sought to answer are;

1. How is the growth performance of *Oreochromis niloticus* influenced by different physico-chemical parameters?
2. What is the effect of feeding different quantities of fish pellets, fertilizing pond Water and liming on the growth performance of *Oreochromis niloticus* in the various culture systems?
3. How is the production of *Oreochromis niloticus* in the various culture systems affected by a combination of fish feed, fertilizer and liming?
3. How do socio-economic characteristics of fish farmers influence the adoption of aquaculture technologies in the study area?

1.5 Research hypotheses

1. Growth performance of *Oreochromis niloticus* in the different culture systems is not significantly influenced by various physico-chemical parameters.
2. The growth performance of *Oreochromis niloticus* in the culture systems is not significantly influenced by varying amounts of fish pellets, fertilizer and lime.
4. A combination of varied fish feed amounts, fertilizers and lime does not significantly increase the growth performance of tilapia in the different culture systems.
4. The level of adoption of aquaculture technologies among the fish farmers is not significantly affected by their social - economic characteristics.

1.6 Significance of the study

The study provides information on the growth performance of *Oreochromis niloticus* cultured in three different culture systems and fed on varied quantities of feed, pond fertilization and liming. The study also provides information on the crucial factors influencing adoption of aquaculture technologies in the study area. The information is very useful to fisheries managers and fisheries extension staff for advising fish farmers on how to increase fish production especially in the constructed fish ponds. Findings from the study very useful to policy makers in coming up with legislation on fish marketing, extension and credit systems to improve aquaculture sector.

The information is a contribution to additional knowledge on the best culture system and the best inputs for fish production. Dissemination of such key production information to fish farmers is important on how they can increase fish production enhancing their incomes, food security and livelihoods.

In addition, the study avails important information on key socio-economic parameters to be considered by planners during planning and implementation of fisheries and other programmes. Such information is also very vital to development partners for inclusion in design reports of various programmes in the counties implementing collaborative projects in different departments. The study information is important to other scholars doing similar studies as source of literature.

The information from the study will also be used by other fisheries service providers and stakeholders in the department of fisheries to strategize the best way to increase fish production especially in the fish ponds.

1.7 Fish growth performance and aquaculture adoption conceptual framework

The independent variables in the growth performance and aquaculture adoption conceptual framework were varied fish feed pellets, different rates of pond water fertilization and liming and a combination of the three inputs. It was anticipated that varying these inputs would cause a change in the growth performance of Nile tilapia in different ways in the various culture systems.

The extraneous variables, dissolved oxygen, temperature and pH are also the main parameters responsible for differences in water quality in the experiment. Water quality is a key consideration of survival of fish in various water bodies. Different species of fish survive better within certain optimal levels of the various water quality parameters. Hence monitoring of water quality parameters in the experiment was important to ensure the different water quality parameters were within the recommended limits for survival of fish. The extraneous parameters could also include certain economic factors, market linkages, demographic factors or other socio – economic factors. These could

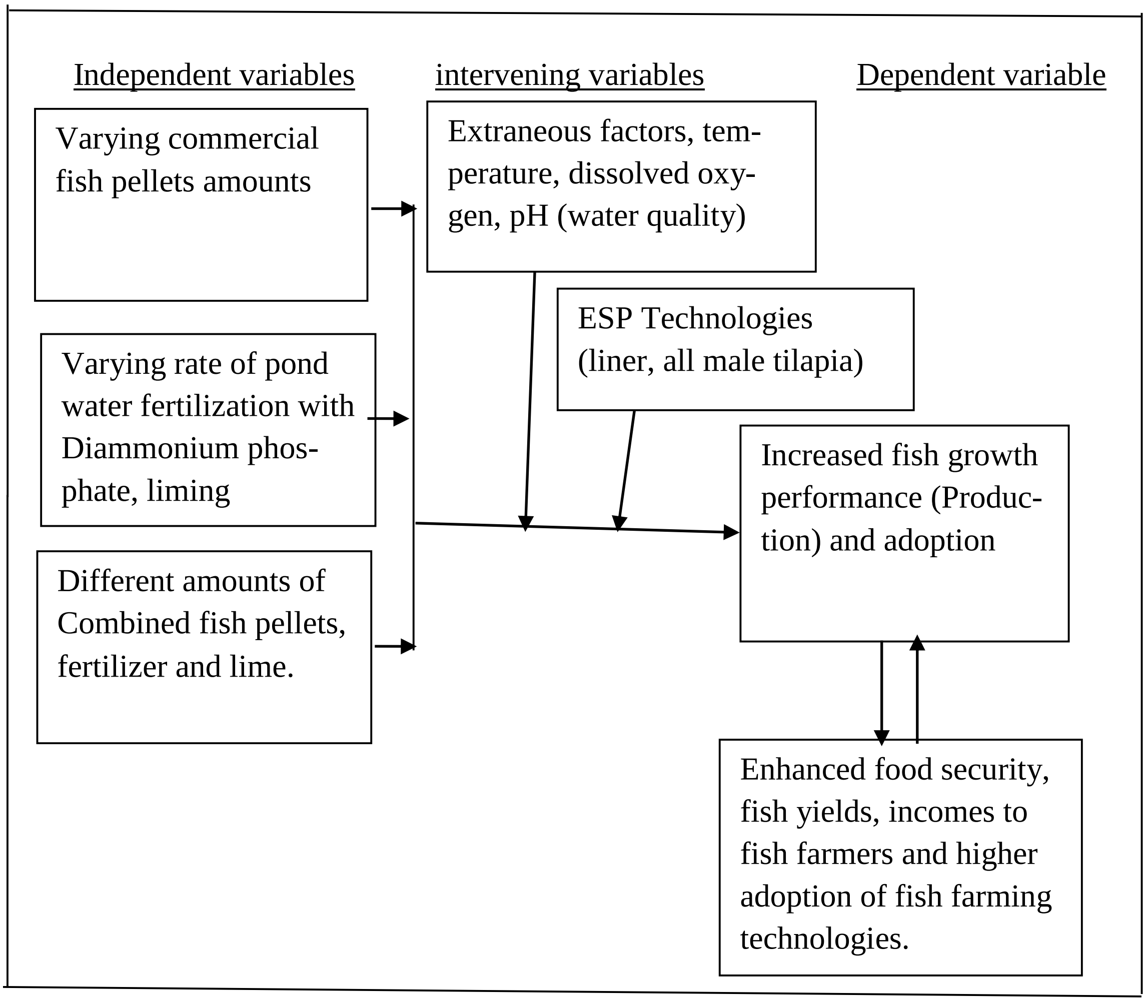


Figure 1.1 Conceptual framework (Modified from Mischke, 2012)

have a direct bearing on adoption of aquaculture in the study area.

The independent variables (varied inputs) and extraneous factors were anticipated to cause a change in the growth performance of Nile tilapia and adoption of aquaculture (dependent variables) enhancing incomes and livelihoods of the farmers and acceptability of aquaculture technologies in the study area. The anticipated change could form a good basis in planning contributing to the bigger economy of the county and the national economy in general. Some of the economic stimulus fish farming technologies identified in the study were liner technology and use of commercial fish pellets for feeding fish.

1.8 Operational definitions of terms

1.8.1 Commercial fish pellets

Commercial fish pellets in the study are high formulated proteinous fish feeds, inorganic in nature and manufactured locally or outside the country specifically for feeding fish. They are in different sizes of 0.5 mm, 1 mm, 1.5 mm, 2 mm, and 5 mm.The commercial fish pellets (feeds) for tilapia usually are supplied with a minimum protein content of 28 % crude protein while for trout is over 35 % crude protein (Munguti *et al.,* 2014)**.** In the study, 30 % crude protein pellets were utilized as feeds.

1.8.2 Diammonium phosphate inorganic fertilizer

Fertilizing pond water with different amounts of DAP fertilizer or manure led to formation of phytoplankton and zooplankton (microorganisms) which acted as supplementary feeds for fish in the pond water increasing productivity of the pond. DAP was preferred to other fertilizers since it releases ammonium and phosphoric ions to the water faster producing the desired results (Ngugi, 2013).

1.8.3 Lime

Liming a pond with different amounts of calcium carbonate or oxide corrects poor water quality conditions by improving pH thus lowering acidity. Fish will feed better in optimal alkaline conditions when fed with varying amounts of fish pellets. Acidic ponds are not productive and the acid causes fish mortality. Liming thus improves productivity of a pond and also kills unwanted germs and bacteria in a pond (Atufa *et al.,* 2015). Liming therefore improves water alkalinity which contributes to good microorganism multiplication in a water body.

1.8.4 Combination of fish pellets, fertilizer and lime

The use of a combination of different quantities of fish pellets (feeds), fertilizer and lime in a pond to rear fish is what is referred to as intensive aquaculture while fertilization of pond water without the use of fish pellets is extensive fish aquaculture. Tilapia species can be cultured using either of the forms of aquaculture. Some farmers use a combination of these inputs while others use either one or two of the inputs. Findings from the study can thus assist the aquaculture specialists in advising fish farmers across the country to attain good returns (Bassey and Ajah, 2010).

1.8.5 Culture systems

The culture system or pond type in the study refers to the medium where fish is reared. The three commonly used media or culture systems in the study are earthen, liner and concrete ponds. Earthen ponds are excavated from the earth's surface and the floor of the pond is made of compacted clay loam soil with a clay content of more than 40 %. Earthen ponds allow for the natural recycling of nutrients between the water and soil interface. Liner ponds in the study are lined using a PVC UV (ultra violet) treated liners of various gauges. They are treated against ultra violet radiation. Concrete ponds are constructed using the normal building materials, bricks, cement, sand and ballast. The liner and concrete ponds are very efficient in preventing water loss (Mischke, 2012).

1.8.6 ESP (Economic Stimulus Project) fish farming technologies

ESP fish farming technologies include rearing of fish using different pond types liner, earthen in swampy areas, rearing of all male tilapia (monosex for faster fish growth) feeding fish using inorganic feeds and fertilization of the pond water. Fish farming Economic Stimulus Project (ESP) was introduced in 2009 by the government through the Ministry of Fisheries Development to revamp and stimulate growth of the aquaculture sector in the country. Initially there were 140 constituencies which had been selected to benefit from the project depending on their aquaculture potential. Farmers in the project were assisted in pond construction, fingerlings, liners and quality fish feeds (Maina *et al.,* 2013).

1.9 Scope, limitations and assumption of the study

The study was conducted in the same locality and the assumption was that, in all the ponds (culture systems), environmental factors and conditions were distributed equally. The research study was undertaken on the assumption that, culture systems and number of fish farmers selected were representative of all other systems and fish farmers in the same region (Charan and Biwas, 2013). The other assumption was that, the survival rate was one hundred percent and predation was zero. The study also assumed that the population where the study was carried out was normally distributed. The study was carried out over a period of three months (90) days and concentrated only in Meru County. Only one strain and species of fish were utilized in the study. Only three inputs and a limited combination of them were used in the study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The chapter brings together some of the studies over the years on production of *Oreochromis niloticus* in different culture systems. The review also looks at fish farming technologies preferred by fish farmers in other countries together with the accompanying reasons and finally identifies the knowledge gaps in the study.

2.1.1 Tilapia culture

Tilapia, a native to Africa and Middle East, has emerged from mere obscurity to one of the most productive and internationally traded food fish in the world (Opiyo *et al.*, 2014). There are about seventy (70) species of tilapia, most of them native to Western African Rivers (Okech, 2004; Ngugi, 2007). Nine species are used in aquaculture worldwide, (FAO, 2007). However, Nile Tilapia (*Oreochromis niloticus*), Mozambique tilapia (*O.mossambicus*) and Blue tilapia (*O.aureus*) are the most commonly reared species. *Oreochromis niloticus* has for many decades been responsible for the significant increase in global tilapia production from freshwater aquaculture and accounts for about 83 % of total tilapia produced worldwide (FAO, 2007).

According to Dey and Paraguas, (2006) the cost of production of tilapia varies with culture systems. In Indonesia it costs an average of US $ 0.63 to produce 1 kilogram of tilapia in cages while in China, it is higher (US $ 1.30). Kamina *et al*., (2014) reports that farmers in the Philippines spend an average US $ 0.99 to produce one kilogram of tilapia in ponds while farmers in Bangladesh spend only an average of US $ 0.16. In both culture systems, feed accounts for most of the total production costs ranging from 34 % (ponds) to 87 % in cages (Bowman *et al.*, 2007).

Although replacing fish meal with blood meal was associated with reduced growth, the economic return was better (P < 0.05). Based on the results, it was economical to use blood meal as a major protein source instead of fish meal in formulating commercial fish feeds for fish production (Kirimi, 2016). Such feed trials investigation coupled with different liming and fertilization rates in various culture systems would yield good baseline information for profitable and viable aquaculture ventures in the country (Munguti *et al*., 2007).

2.1.2 Inputs and culture systems in aquaculture

Organic materials are not recommended for fertilizing ponds as excessive amounts may lower dissolved oxygen to a critical level, possibly killing fish, however combining organic and inorganic fertilizers, performance of tilapia is enhanced and fish production is high (Bocek, 2009). When the culture systems are fertilized, production of natural food increases in the systems, phytoplankton, zooplankton and insects also increase leading to more live food for the fish ultimately increasing fish production (Zikria *et al*., 2012). They are all part of a complex food web converging toward fish production (Bocek, 2009). In his study on the performance of *Oreochromis niloticus* using organic and inorganic fertilizers, (Bocek, 2009) found that when the two types of fertilizers were combined, fish production was highest in these particular ponds (Alam *et al.*, 2014). *Oreochromis niloticus* feeding habit changes from carnivorous when young (7 – 33 mm) consuming zooplankton, aquatic insects and detritus which make up about 26 % of their stomach contents to omnivorous (Shaker, 2008).

Combination of the inputs especially various proteinous dietary compounds increases the effects of the inputs (Aladetohun *et al.*, 2013). The proteinous fish feeds serve also as sources of water fertilization in the culture systems especially left overs when the fish is not able to finish all the feeds in water and the excess feeds fall at the bottom of the culture systems or ponds. Kassim *et al*., (2015) investigated growth performance of improved (F_5 and F_6) and unimproved strains of tilapia with a combined commercial fish feed at 5, 7 and 9 fish/m^3 stocking density in 9 m^3 hapas suspended in a 700 m^2 pond at Bunda fish farm in Malawi. They reported that, the highest final weight was noted at a stocking density of 5 fish/m^3 with an average weight of F_6 being 28.1 g, followed by the F_5 (24.9 g) and the unimproved (24.0 g) strain. The improved strains had a higher final mean weight (F_6: 23.41 g, F_5: 21.84 g) than the unimproved strain (18.70 g). The improved strains of tilapia have a higher growth rate and improved taste of the fillets. Most hatchery operators specialize in producing fingerlings from the improved strain and sell to farmers for rearing in grow out ponds.

Most fish farmers still continue to procure unimproved strains of tilapia from their neighbours for stocking in their ponds. This encourages inbreeding and the final result is stunted uneconomical fish in the market (Ngugi, 2007). Alam *et al*., (2014) note that fish farmers can change their mind sets if research findings including fish growth performance trials of the improved tilapia in earthen, liner and concrete ponds using different inputs can be availed at various data centres in the counties. When ponds are fertilized, there is increased multiplication of phytoplankton and zooplankton increasing available live feeds in the water which serve as supplementary feeds for fish (Opiyo *et al.*, 2014). Kirimi, (2016) observed that pond water turns green as water fertility increases due to the high density of phytoplankton.

In Ghana, Duodu (2015) carried out a study to quantify the performance of fish cultured in fertilized ponds and fed half the recommended ration of formulated feed and the cost-effectiveness of using inorganic fertilizers to improve productivity of tilapia raised in ponds. Three of the ponds were unfertilized while the other three were fertilized. Fertilized ponds were fed half (1.5 – 3%) of the recommended ration whilst unfertilized ponds were fed strictly according to response. The results of the study showed a comparable growth of 202.9±23.8g and 204.2±36.3g between half ration and full ration ponds respectively. A similar observation was recorded for the Total Weight Gain (kg), Specific Growth Rate (%/day), Feed Conversion Ratio and Feed Intake with corresponding values of 101.7±35.6kg (H); 101.9±34.0kg (F), 1.2±0.2 (H); 1.2±0.2 (F), 1.2±0.3 (H); 1.1±0.2 (F), and 0.6±0.3 (H); 0.7± 0.5 (F) for half and full ration ponds, respectively. When the ponds are fertilized, less feeds which account for about 50 % in aquaculture are used to feed the fish while more feeds are utilized when the pond water is not fertilized. Cost of production of fish will therefore be high for unfertilized ponds.

Shamsuddin, (2013) and Youssouf, (2013) reported a Food Conversion Ratio (FCR) in monosex *Oreochromis niloticus* in earthen ponds of 1.51 and a production of 19076 kg ha^{-1} using a commercial fish feed. Investigation in other culture systems could complement aquaculture fish farming data and statistics creating good reference material for aquaculture planning (Alam *et al.*, 2014).

2.1.3 Water quality parameters

The most important water quality parameters among others considered in rearing fish are alkalinity or pH, dissolved oxygen and temperature. Different species of fish survive optimally in different ranges of the stated parameters (Ngugi, 2013). It is therefore important to monitor the parameters throughout the experiment to ensure they are within the accepted limits for optimal survival of fish (Opiyo et al., 2014).

2.1.3.1 pH

Tilapia can survive in a wide range of water acidity; however the recommended pH for good growth of tilapia is 6.5 to 9. Acidic water will not support the growth of phytoplankton, zooplankton and detritus digesting bacteria, which are important as they collectively provide an environment conducive for fish growth (Ngugi, 2013).

Addition of lime to the ponds increases pH and hence improve water quality and provide a good environment for multiplication of microorganisms leading to availability of more feeds in the culture systems, further (DAP) application increases water fertility of the culture systems leading to higher multiplication of zooplankton and phytoplankton in the systems therefore increasing supplementary feeds to the fish in the culture systems. Fish production per unit area has been found to increase with addition of lime and fertilizer as fish get extra live feeds from water in the culture systems, (Shaker, 2008). According to El-Sherif and El-Feky, (2009), who investigated growth performance of tilapia fingerlings using four (4) levels of pH, 6, 7, 8 and 9, growth of those reared at pH 6 was significantly decreased (P less than 0.05) than those reared at pH 8 and 9.

2.1.3.2 Dissolved oxygen

Tilapia is able to survive levels of dissolved oxygen below 2.3 mg/L as long as temperature and pH remain favourable (Ngugi, 2013) and (NARDTC, 2013).

According to Abdel-Tawwab, (2015) growth performance of *Oreochromis niloticus* at three levels of dissolved oxygen (low: 0.1–1.5, medium: 2.5–3.0, and normal: 6.0–6.5 mg/L) and two sizes (3.7 and 12.9 g) within quadruplicate, all the fish performed better at the normal dissolved oxygen (6.0–6.5 mg/L) compared to those reared at low and medium dissolved oxygen. Kurt, (2015) reported good growth performance of *Oreochromis* fingerlings of 9.39 ± 0.19 g in 10 weeks at a pH of 7.74 ± 0.25, dissolved oxygen 5.14 ± 0.53 compared to fish reared at a pH of 5.7 which attained a weight of 6.87 g, at dissolved oxygen of 4.25 ± 0.93. Low dissolved oxygen causes fish to be less active in feeding leading to slow growth rate (Ngugi, 2013)

2.1.3.3 Temperature

Oreochromis niloticus does not grow well at temperature below 16 degrees Celsius due to decreased metabolism, activity and feeding (Vander *et al.,* 2013). Reproductive activities occur above 22 degrees Celsius (Abdel, 2008). In temperate and some sub-tropical regions, their culture is highly affected by sensitivity to low water temperatures leading to poor growth and mass mortality during over-wintering (Charo-Karisa *et al.,* 2005). Fish naturally tend to select the habitat that is most suitable for their physiological requirements. This behavior is known as 'habitat selection' or 'enviroregulation' (Ali *et al.*, 2013, BMP, 2013). Therefore, fish move into deeper water when surface water temperature decreases or increases beyond their preferred range (Charo-Karisa *et al.,* 2005). So, fish ponds should be deep enough to meet temperature demands and other habitat requirements of cultured fish, especially in arid areas where diurnal and seasonal fluctuations in water temperature occur (Ali *et al.,* 2013). According to Veeramani and Santhanam (2015), the optimum temperature in cold areas of India for a growth of 250 gms in six months of *Oreochromis niloticus* was 22.3 to 36.4 degrees Celsius. Growth performance of tilapia was best at 32 degrees Celsius ($p < 0.05$).

One major constraint to the global expansion of tilapia farming is their sensitivity to low ambient temperatures (Charo-Karisa *et al.,* 2005). However acclimatization to lower temperatures before cold stress can improve the cold tolerance ability of *O. niloticus* and enhance fish production. Therefore it is always necessary to acclimatize fish before stocking for any experimental tests to avoid shock to the fish, the shock may lead to fish mortality. Fish reared under mid-summer conditions died between 13.6 ºC and 8.6 ºC while those reared under autumn conditions died between 11.7 ºC and 7.5 ºC when the effects of genotype, age, size, condition factor, and diet (natural phytoplankton versus formulated protein pellets) on low-temperature tolerance of juvenile Oreochromis niloticus were studied in Abbassa, Egypt at the World Fish Centre (Noble, 2007) over a period of 42 days.

Frida, (2014), reports an ambient temperature of 21.8 degrees Celsius for a 20 gms gain in each of 100 Oreochromis niloticus fingerlings in 21 days in Nairobi, Kenya. She used three levels of a proteinous diet (15 %, 25 % and 35 % Crude protein). She deduced that, as the level of the crude protein increased, growth performance of tilapia fingerlings improved (($P < 0.001$). However, at 21.1 degrees Celsius, the fish only gained 16.8 gms during the 21 days experimental period with the same commercial feed and feeding frequency of two times per day.

At very low temperatures, Lall, (2009) reports that, metabolic rate in fish is reduced and fish feed less. This slows growth performance of fish hence fish production especially for tilapia fish, which is a warm water fish but trout fish metabolic rate would not be affected at low temperatures since it's a cold water fish (Mwangi, 2015).

2.1.4 Effect of various types of fish feeds on growth performance of tilapia in different culture systems

In semi-intensive and intensive aquaculture systems, feed costs typically account for between 40 and 60 percent of production costs (De Silva and Hasan, 2007). In order to ensure profitability, it is imperative that farmers have access to good quality feeds at reasonable prices, and that they optimize their feed use by instituting appropriate on-farm feed management practices (FAO, 2013) and (Abolelghany *et al.*, 2020).

Growth performance of various species of fish is affected by the type of feed and level of crude protein in fish diet (Bureau, 2006). Good growth in tilapia species occurs from fish diets with over 28 % crude protein while in other species of fish like trout, good growth takes place from a proteinous fish diet containing 40 % crude and above (Munguti *et al.,* 2014).

In Ghana, *Oreochromis niloticus* fingerlings (tilapia) grown in cages and hapa-in-pond culture systems at a stocking density of 32 fish per cubic metre and fed a commercial fish feed of 36 crude protein, fish grown in cages attained a weight of 336 gms in 24 weeks compared to fish in hapa-in-pond culture system which attained a weight of 201.6 g over the same period (Emmanuel, 2013). When fish are not crowded in a pond or cage, there is less competition for feeds and space with fish feeding easily to satiation. In a crowded pond or cage, there is stiff competition for the limited feeds and only the strong fish is able to survive under such circumstances. This leads to many weak fish which are stunted and emaciated (Ngugi, 2013)

Reducing feeding rates is another important factor affecting the economic return of tilapia in semi-intensive culture systems. According to Abdel, (2008) most efficient system for Nile tilapia reared semi-intensively is to grow the fish up to 100-150 g with fertilizers alone, followed by feeding them with supplemental feeds at 50% satiation. He found that feeding the fish before they reach this size was wasteful. In Egypt, for example, tilapia farmers generally use a single application of sometimes DAP and urea at rates of 35 and 25 kg/ha, respectively) before fish stocking. In addition, many farmers start feeding their fish about one month after stocking (El-Sayed, 2007). He further observed that, adoption of both fertilization and supplemental feeding would be more appropriate and cost-effective and recommends that natural food be used during early growth stages, whereas supplemental feeds be added at later fattening stages. Cost of production of fish is reduced since the farmer procures less feeds and there is no significant change in fish production at the end of the grow-out period (Ogbonna *et al.*, 2014).

Dhirendra, (2007) reports a final weight gain (growth performance) in tilapia of 312±1.8 g and mean daily weight gain of 1.8±0.0 g day-1 when all male *Oreochromis niloticus* fingerlings were stocked in six 280 square metre earthen ponds at a stocking density of 3 fish per square metre for 90 days in fertilized ponds throughout the culture period, fed from day 80 with a commercial fish feed of 26 % crude protein while those in ponds fertilized until day 80 and fed with a commercial fish feed starting from day 80 attained only a mean final weight of 248 ± 17.5 g and mean daily weight gain of 1.4 ± 0.2 g day-1. Net tilapia yield in treatments 1 and 2 was 16.7 ± 0.4 and 13.0 ± 1.4 t ha-1 year-1, respectively. Widening the scope of investigation to cover liner and concrete ponds can yield crucial information on the performance of *Oreochromis niloticus* in different culture systems commonly utilized by fish farmers in the field.

Okonji *et al*., (2013) reports an increase of over 10 times of growth performance (mean weight) of all male *Oreochromis niloticus* fingerlings when they were reared in four outdoor concrete tanks at a stocking density of 4 fish per square metre for 24 weeks in Nigeria. The fingerlings which were fed with a 36 % crude protein diet attained a mean weight of 1.260 Kg/M^3 at the end of the 24 weeks while those which were reared only in fertilized pond with algae without feeding with a commercial fish feed attained a weight of 0.115 Kg/M^3 . The effect of feeding the tilapia fingerlings with a commercial proteinous diet therefore increased their growth performance 10 fold as opposed to the treatment in which fish was not fed. Since growth performance of *Oreochromis niloticus* was only tested in concrete ponds, performance in liner and earthen ponds ought to be investigated to find out the culture system where tilapia performs better. Such information is crucial while advising or training aspiring fish farmers who intend to set up commercial fish farms.

2.1.5 Fertilization and liming in different culture production systems of fish

Fertilization and liming of a culture production system of aquatic organisms, including fish, increases productivity per unit area of the system (FAO, 2019). When water in a culture system is fertilized and limed, microorganism numbers increase in the system increasing available live feed for fish leading to more fish production especially when artificial commercial feeds are added to the system as supplemental feeds (Dong, 2008) and (FVG, 2016).The use of inorganic and organic fertilizers in extensive and semi-intensive production systems is a well-established practice; however, considerable differences exist in the type of fertilizers used and in their availability, cost, and application rates, (Tacon *et al.*, 2011).

Emphasis to find out the qualitative and quantitative relationships between natural productivity and the impact that the use of supplemental commercial feeds have on nutrient cycling and retention in the culture may be important in enhancing production efficiencies in extensive and semi-intensive production culture systems (FAO, 2013). The comparative role of commercial fish feeds versus fertilization of fish culture production systems on the nutrition of the aquatic farmed organisms is poorly understood. Commercial fish feeds often play a dual role by providing nutrition to the aquatic organisms being farmed and as a nutrient source to stimulate natural productivity in aquatic systems (Tacon, 2011). A better understanding of these dynamics is crucial in improving nutrient retention in the farmed species and the culture system, enhancing feed formulation, reducing feed costs, increasing efficacy of feed management and efficient feeding schedules (Romana-Eguia *et al.*, 2013).

According to Waidbacher *et al.*, (2007), there was variation in growth performance of *Oreochromis niloticus* where in some ponds tilapia fingerlings were fed with a 24 % crude protein commercial diet in a fertilized system while in others, the system was not fertilized in cage – cum – open pond system in Kenya for 114 days . In the fertilized system, there was significant weight gain ($P<0.05$) of 134.8 g compared to those reared in unfertilized culture system where only a weight gain of 119.7 g was recorded.

According to San, (2008), *Oreochromis niloticus* which were reared in a fertilized earthen pond and fed on a commercial fish feed with addition of vegetables in a polyculture with common carp, tilapia attained a final total weight gain of 21.2 kg ha^{-1} day^{-1}resulting to a yield of 3,120 kg ha^{-1} in four months ($P<0.05$). In ponds which were not fertilized, fish attained a growth performance of 6.17 kg ha^{-1} day^{-1}resulting in a yield of 2,470 kg ha^{-1} over the same period in Colombia. Water quality (pH, water transparency, water temperature and dissolved oxygen) were within the acceptable range in all the treatments. Economic returns were also higher for the fish reared in the fertilized culture production system.

Saad *et al.*, (2014) reports increase in growth performance, yield and net returns of *Oreochromis niloticus* when it was reared in fertilized and limed earthen ponds compared to unfertilized ponds in Egypt. *Oreochromis niloticus* fingerlings of a mean weight of 29.9 g stocked in different ratios in fertilized and unfertilized open ponds and cages and fed a commercial diet at 1.5 % body weight for 160 days, fish in limed and fertilized ponds produced higher economic returns 22550 and 23220 LE/Faddan compared to 17828 and 13360 LE/Faddan which had not been fertilized with no liming. Studies by Atufa *et al.*, (2015) on growth performance of 4gms *Oreochromis niloticus* fingerlings in Pakistan in inorganic fertilized earthen ponds which were limed and fish fed on a commercial diet at the rate of 3 % body with a stocking density of 1200/acre. Fish attained a weight of 373.56 kg/acre/year compared to unfertilized ponds which were not limed where fish attained a weight of 286.40 kg/acre/year. Addition of all the required inputs in the culture production systems increases water quality, microorganisms and hence live feeds for the growing tilapia fingerlings. Food Conversion Ratio and Specific Growth rate per fish also increase leading to good growth performance of fish (FAO, 2013). Many fish farmers in the field use one or more of these inputs in the culture production systems to boost fish production. Research findings on other culture systems is limited for informed decision making and planning in the aquaculture sector development especially in developing countries.

2.1.6 Production of *Oreochromis niloticus* in different culture systems

Aquaculture, compared to crop and animal farming, is much more diverse and varied. There are many different species that are cultured each with different ecological requirements (Mbugua, 2007). They therefore have different feeding and breeding requirements as well as water quality. Production systems have therefore been developed to meet both the economic needs of the producer and the requirements of the species to be cultured (Mischke, 2012). Depending on the planned level of production and the resources available, the producer will make a choice from the following;(a) extensive production culture system, with a production which ranges between 500 and 1500 Kg/Ha/year in Kenya, (b) semi – intensive culture system with a production of 1 - 3 Kg/m^2/year and (c) intensive production culture systems with a production ranging from 10 to 70 Kg/m^2/year. This depends on the management levels employed by individual producers. This production can go higher with better management and quality feeds (Kurt, 2015) and (Harondex, 2013).

Fish is reared in various culture systems depending on the species of fish being cultured. The systems commonly used by fish farmers are earthen ponds, liner, concrete, raceways, plastic tanks, metallic tanks, cages and hapas (Mbugua, 2007). Growth performance of fish varies with the type of culture system used to rear fish. Dagne, (2013) reports that, growing male mono-sex *Oreochromis niloticus* for 6 months is more profitable than growing mixed sex tilapia in earthen semi – intensive culture system ponds in Egypt.

According to Dagne, (2013), there was variation in growth performance of tilapia when all male mono-sex fingerlings were grown in earthen culture ponds at a stocking density of 2 fish per m^2 and fed with a commercial fish feed at the rate of 5 % body weight for 240 days and mixed sex tilapia also subjected to the same treatment. Mono – sex male fingerlings attained a mean weight of (176.20 ± 18.01) g while mixed-sex attained ((108.20 ± 15.4) gms, P<0.05. He further deduced that, there was a difference in attaining the optimum net return in culturing *Oreochromis niloticus* as male mono-sex and mixed-sex in earthen ponds culture system.

The male mono-sex group attained its optimum net return after 6 months of culture periods, while the mixed-sex group attained after 8 months. Therefore, culturing for extra two months in the later case showed a 32% decline from the optimum net return. Investigation of growth performance and other culture systems is essential information for dissemination to fish farmers and extension staff (Dagne, 2013).

According to Mondal *et al.,* (2010) growth performance is better in open earthen ponds compared to cage culture system. He observed that when tilapia was stocked at a stocking density of 50 fish per 80 square metre in open ponds and cages and fed with a diet containing 35 % crude protein, at a rate of 5 % body weight for 90 days, fish in open pond performed better, had a feed conversion ratio (FCR) of 0.85 and in cage FCR offish was 0.75, ($P<0.05$). Probably the fish in the cage was too crowded increasing competition for the available feeds while in the open pond competition is not so high due to availability of more space and feeds. Investigation of growth performance of tilapia in liner and concrete is also necessary to gauge the capacity and effectiveness of the other culture systems suitable for aquaculture planning.

Khan and Hossain, (2008) report higher growth performance in *Oreochromis niloticus* when it is fed with a commercial fish feed compared to use of local fish feeds, mustard oilcake and rice brain. They reared tilapia fingerlings in nine seasonal small ponds for three months in Bangladesh University farm under three treatments; (i) pond water was fertilized using DAP inorganic fertilizers, no supplemental feed was given to fish (T1), (ii) pond water was fertilized and fish fed with rice bran and mustard oilcake (T2), (iii) in addition to fertilization of pond water, fish were fed with a commercial fish feed of 26 % crude protein (T3). Significantly highest production (3941.50 kg/ha in three months) was found in T3 followed by T2 (1845.5 kg/ha) and T1 (972.50 kg/ha).

Similarly, significantly highest net return (Tk. 61805.00/ha with benefit cost ratio of 1.45) was found in T3 followed by T2 (Tk.1339.00/ha with benefit cost ratio of 1.01) and T1 (Tk. 201.50/ha with benefit cost ratio of 1.00). Use of commercial fish feed therefore increased production by more than half compared to the use of local fish feed of mustard oilcake and rice bran (Hossain, 2013). The higher the harvest (production) the higher the returns or profit (Akangbe, *et al.*, 2015). Since growth performance was investigated in simple seasonal earthen ponds, the investigation can be expanded to cover concrete and liner ponds including other culture systems for more informed decisions especially in aquaculture planning.

According to Gomez-Marquez *et al*., (2015), all male *Oreochromis niloticus* tilapia fry of initial weight 0.21grew to a weight of 192.2 gms compared to mixed sex tilapia fry which grew to a weight of 131.4 gms in six concrete ponds at a density of 4 fish per metre square, fed the same commercial fish feed for six months in Mexico. At maturity the mixed sex fingerlings spend a large portion of their energy in reproduction while the monosex all male tilapia fingerlings utilize all their energy in growth hence the higher increase in weight. Growth performance of tilapia in earthen and liner culture systems is crucial in understanding the production capacities and capabilities of other culture production systems.

2.1.7 Growth performance of O*reochromis niloticus* under a combination of feed, fertilization and liming of pond

Most commercial fish farmers producing fish under the intensive culture production system utilize three types of inputs; feed, fertilizers and lime in their ponds to increase fish productivity. Effect of the combined use of some of the inputs on the growth performance of fish has been studied by various scholars. Bassey and Ajah, (2010) report a weight gain of 420 gms of tilapia fish when tilapia fingerlings were reared for six months in limed earthen pond and fish fed with a commercial fish feed of 36 % crude protein in Turkey compared to a weight gain of only 109 gms in culture systems where fish were reared in ponds with only liming treatment.

According to Opiyo *et al*., (2014), *Oreochromis niloticus* grew to a mean weight of 122.47 gms when the fish was reared in fertilized earthen pond and fed with a commercial fish feed of 32.7 % crude protein for six months in Kenya, compared to fish which was fed with a local fish feed of only 16.0 % crude protein where fish attained only 91.5 gms, ($P<0.05$). Effect of additional of other inputs, lime in different culture systems should also be investigated to broaden the scope of investigation inorder to appropriately advice farmers and extension staff.

Karim, (2013) reports a mean weight gain of of 323.68 when tilapia fingerlings were reared for four months in fertilized, limed earthen ponds and fish fed four times daily with a 30 % commercial feed in Bangladesh compared to a weight gain of 294.55 when fish was fed three times and 244.72 g when fish was fed two times daily. The higher the frequency of feeding the high the production and hence more returns per unit area. Fish feed on small quantities of feed but more regularly in a day, however feeding frequency varies with the environmental conditions and water quality from region to region, (Piniji, 2013; Asuwaju, 2014). Investigation in other culture production systems with application of the three inputs is necessary to come up with an informed decision for planning purposes in the aquaculture sector.

In India, tilapia reared in earthen ponds which had been treated with all the inputs, fertilizer, lime and fish fed with artificial commercial feed, performed better with a specific growth rate of fish of 2.782 compared to earthen pond which was fertilized only where the specific growth rate was 2.673 and 2.628 where there was no input which was added, fish was just fed with the commercial feed only (Suresh *et al.*, 2013). Addition of all the inputs increases tremendously the availability of micro-organisms in the pond water increasing live feed for the fish. Fish therefore grow faster increasing fish productivity per unit area. Performance of tilapia in other culture production systems, liner and concrete ponds should also be tested for improved data base in aquaculture sectorial planning.

Sultana *et al*., (2013) on the growth performance of three strains of *Oreochromis niloticus* when they were fed with two different commercial fish feeds in Pakistan for four months indicated that fish fed on specifically prepared fish feed with verified crude protein of 30 % attained a final mean weight gain of 123.48 g compared to fish fed on local fish feed where weight gain was 111.82 g. Recorded specific growth rate for the two treatments were 3.09 and 2.97 respectively and food conversion ratio were 1.51 and 1.41. Hence the higher the crude protein in the diet, the higher the growth performance of fish. According to Asase, (2013), *Oreochromis* niloticus fingerlings stocked in 8 m3 cages at densities of 50 fish/m3, 100 fish/m3 and 150 fish/m3 and fed a commercially extruded diet (30% Crude Protein) in Ghana for 177 days, differences in growth performance of tilapia (weight gain and final weights) at these densities were significant ($p < 0.05$). Fish stocked at 50 fish /m3 exhibited the highest average weight gain 271.98 ± 0.39 g while fish stocked at 150 fish/ m3 had the lowest 169.15 ± 0.49 g.

2.1.8 Technology adoption

Loevinsohn *et al*., (2013) defines innovation as the mode of producing goods and services, including methods of organization as well as physical technique. According to these authors innovation is new to a particular place or group of farmers, or represents a modern use of technology that is currently in use within a particular area or among a group of farmers in a given locality.

Innovation itself is aimed at improving a given situation or changing the status quo to a more desirable level (Langy and Mekura, 2006). It aids the user in doing work easier than he would have in the absence of the innovation hence it helps save labour costs and time (Bonabana, 2007). Adoption on the other hand is also defined in different ways by various authors. Several studies on modern technology have been conducted using earth culture production systems where fish production has been proved to increase with modern aquaculture technologies application (Lavison, 2013). However, technological studies have not been expanded to cover all culture production systems like liner and concrete culture production systems.

According to Feder and Zilberman (2008), adoption is categorized into two; intensity of adoption and rate of adoption. The later is the relative rate with which farmers adopt a technology, has as one of its pillars, the element of 'time'. Intensity of adoption on the other hand refers to the level of use of a given innovation in a given time period. According to Doss, (2009) adoption of improved seed in a survey done by CIMMYT, categorized farmers as adopters if they were using seeds that had been recycled for a long period of time from hybrid ancestors. In other studies, uptake was associated with extension service recommendations of using only modern certified seeds (Ouma, 2006; Doss, 2009; Bisanda, 2008). Therefore definition depends on the fact that the farmer is an adopter of the technologies or non-adopter taking values zero and one or the response is continuous variable (Challa, 2013; Rogers, 2009). The relevance of each approach depends on the particular context under consideration (Doss, 2009; Jumnongruk, 2005).

A lot of researchers use a dichotomous variable approach in the farmers' decisions of new technology adoption. According to Jain *et al.,* (2009), this approach is necessary but not adequate because the dichotomous response reflects the status of awareness of improved technology rather than the actual adoption. Researchers should thus accurately state how they are defining this term, technology adoption so that they can come up with relevant tools for measuring it (Jain *et al.*, 2009).

2.1.9 Aquaculture modern technologies

Technologies and systems used in fish farming have developed so fast in the past fifty years (Chakraborty, 2013; Fessebaye, 2006). They vary from very simple facilities of family ponds for domestic consumption in tropical countries, to high technology systems (FAO, 2013). These systems include intensive closed systems for export production, biofloc and recirculating aquaculture systems (FAO, 2013). Much of the technology used in aquaculture is based on modifications that improve growth and survival rates of the target fish species.

Immense understanding of the complex interactions between nutrients, bacteria and cultured organisms, together with advances in hydrodynamics applied to pond and tank design, have enabled the development of closed systems. These have the advantage of isolating the fish farming systems from natural aquatic systems, thus minimizing the risk of disease or genetic impacts on the external systems (FAO, 2013).

The fast growth of the aquaculture industry has been enabled through the expansion of fish farming production areas (Oyinlola *et al.*, 2018), intensification of production systems (Joffre *et al.,* 2017), adoption of new innovations, and systematic improvement of existing technologies that brought control over husbandry and production processes

(Kumar and Saurabh, 2014; Henriksson *et al.,* 2018; Kumar *et al.,* 2018). Fish farming offers great scope for technical innovation to further increase animal protein supply and resource efficiency (Waite *et al.,* 2014).

Recent studies indicate that investments in new production systems, management practices and new products result in substantial benefits to consumers and producers (Kumar and Engle, 2016; Kumar *et al.,* 2018). However, there is still incoherent understanding of technological change in aquaculture development in Africa (Engle, 2017)

2.2.0 Determinants of aquaculture technology adoption

Several studies have been conducted on factors that influence aquaculture technology adoption (Nyman, 2008). According to Loevinsohn *et al.,* (2013) and Khan, (2013), farmers' decisions whether to adopt new technologies are conditioned by the changing interaction between characteristics of the technology itself and a myriad of conditions and circumstances. Diffusion results from a series of personal decisions to start using predetermined the new technology, decisions resulting from a comparison of the uncertain gains of the new innovation compared with the uncertain price of adopting it (Hall and Khan, 2006). In depth understanding of the variables determining this choice is important both for the generators and disseminators of such innovations and the economists studying the determinants of adoption (Hall and Khan, 2006).

Conventionally, economic analysis of technology adoption has attempted to explain adoption behavior in relation to individual characteristics and endowments, institutional constraints, imperfect information, risk, uncertainty and input availability (Koppel, 2009; Rousan, 2007)). Recent studies have included social networks and learning in the class of factors determining adoption of technology (Uaiene *et al.*, 2009) and (Eze and Akpa, 2010). Certain studies categorize these factors into different groups. Akudugu *et al*., (2012) categorizes the determinants of aquaculture technology adoption into three categories namely; social, economic, and institutional factors.

Harper *et al.*, (2009) and Lavison, (2013) categorized the factors determining adoption of technologies into physical, social and economic categories, (Feder and Zilberman, 2008) classified them into, managerial structure, farmer characteristics, farm structure, and institutional characteristics (Ogunfiditimi, 2007) grouped them into ecological, informational and economic, while (Fasikim, 2008) categorized them into production, human capital, policy and natural resource characteristics. Inspite of the fact that there are so many methods for grouping determinants for technology adoption, there is no clear cut distinguishing feature between factors in each category (Lavison, 2013). Classification of the factors is done to suit the current technology being examined, the researcher's preference, locality, or even to suit customers' needs (Bonabana, 2007). The level of education of a farmer has been categorized as a human capital by some researchers while others group it as a household specific variable. This study will review the factors determining adoption of aquaculture technology by categorizing them into technological factors, economic factors, institutional factors and household specific factors. This will enable a depth review of how each factor influences adoption.

2.2.1 Technology factors

According to Bridges, (2011), characteristic of an innovation is a precondition of its uptake. The degree to which a would be adopter can try something out on a small scale before adopting it completely is a key determinant of technology adoption (Doss, 2009). Mignouna *et al*., (2011) reports that technology plays a critical role in adoption decision process in studies on determinants of adopting Imazapyr-Resistant maize (IRM) technology in Western Kenya (Agbamu, 2006).

They noted that farmers who perceive the technology being compatible and consistent with their needs to their environment are more likely to adopt since they consider it a viable investment. Farmers' perception about the performance of the new technologies greatly influence their decision in their uptake. Adesina and Zinnah, (2010), Gregory, (2007) report that farmers' perception of characteristic of modern rice strain greatly influenced their decision in accepting it. Similar results were reported by (Jatto *et al*., 2013) while studying perception of farmers towards uptake of Aquaculture technologies in Cameroon. Their study showed that, perception of fish farmers towards aquaculture enhanced its uptake. It is thus very crucial that for any modern technologies being introduced to farmers, they be involved in their evaluation to find their suitability to their circumstances (Karugia *et al*., 2006) and (Agbamu, 2006).

2.2.2 Economic factors

Size of farm plays a crucial role in aquaculture and agricultural production and thus adoption process of modern technologies (Ahmed, 2009). Due to the ever rising population, land for aquaculture and agricultural farming is limited. Farmers have intensified their production systems to ensure available land is used economically and profitably. Several authors have analyzed size of farm as one of the most important factor of new technology uptake and production. Size of farm can determine and in turn be affected by the other determinants influencing production and adoption (Lavison, 2013). Certain new technologies are referred to as 'scale-dependent' due to the great importance of size of the farm in their adoption (Bonabana, 2007). Several studies have reported a positive relation between size of the farm, adoption and production of modern agricultural technologies (Ahmed, 2009; Uaiene *et al*., 2009; Mignouna *et al.,* 2011; Lowenberg, 2011).

Additionally, commercial technologies such as animal traction or mechanized equipment call for economies of size of farm to ensure profitability (Feder and Zilberman, 2008). Certain studies have shown a negative influence of size of farm on adoption of modern agricultural technologies (Allahyari, 2010).

Small size of farm may offer an incentive to uptake of a new innovation especially in the case of an input-intensive technology such as land-saving or a labour-intensive innovation. According to Harper *et al,* (2009), farmers with small farms may adopt land-saving innovations such as zero grazing, fish farming and greenhouse technologies among others as an alternative to increased agricultural yields. Some studies have reported neutral relationship or insignificant difference with adoption (Susan, 2014). A case study by Bonabana (2007), Samiee *et al.,* (2009) and Goswani *et al.,* (2010) concluded that size of farm did not affect Integrated Pest Management uptake implying that IPM dissemination to farmers may take place inspite of farmers' level of operations.

Thus in relation to size of farm, innovation uptake may best be explained by measuring the proportion of area of total land suitable for the new innovation (Bonabana, 2007). The key factor influencing adoption of a new technology is the net gain to the farmer from uptake, inclusive of all costs of using the innovation (Foster and Rosenzweig, 2010). The price of adopting agricultural new technologies has been found to be an obstacle to technology uptake. The removal of subsidies on prices of fertilizers and seeds from the 1990s as a result of the World Bank-sponsored structural adjustment programs in sub-Saharan Africa has amplified this challenge (Muzari *et al*., 2013).

Past studies on determinants of innovativeness globally have also reported high cost of innovation as an obstacle to adoption. According to Makokha *et al*., (2001), determinants of manure and fertilizer use in maize farming in Kiambu Kenya, unavailability of demanded packages, untimely delivery, high cost of labor and other inputs were reported as the main obstacles to fertilizer adoption. Ouma, (2006) reported cost of hired labour in Embu County Kenya also as one among other factors hindering uptake of hybrid seed and fertilizer. Wekesa *et al.,* (2003) while analyzing factors influencing adoption of improved maize strains in coastal lowlands of Kenya, found that unavailability of seeds and high cost were the factors responsible for the low rate of uptake. They further reported that off farm income and reliable sources of credit had a positive impact on technology uptake.

Explanation for this phenomenon is due to the fact that, off-farm income acts as an important strategy for resolving credit challenges faced by the rural smallholder farmers in several developing countries (Reardon *et al*., 2007). Off-farm income acts as a substitute for borrowed capital in rural economies where credit facilities are either dysfunctional or missing (Diiro, 2013; Ellis and Freeman, 2004). According to Diiro, (2013), off-farm income is expected to accord farmers liquid capital for procuring productivity enhancing inputs such as fertilizers and improved seeds.

While analyzing the impact of off-farm income on the intensity of innovation on improved maize varieties and the productivity of maize production in Uganda, (Diiro, 2013) reported a higher intensity adoption and expenditure on procured inputs among smallholder farmers with off-farm income compared to those without off- farm income.

However not all innovations have demonstrated positive relationship between off-farm income and their uptake. Certain studies on innovations that are labour intensive have demonstrated negative relationship between off-farm income and uptake (Diiro, 2013).

According to Goodwin and Mishra, (2006) the pursuit of off-farm earnings by farmers may undermine the uptake of new technologies by reducing the amount of smallholder labour assigned to agricultural enterprises. Conventionally, economic analysis of technology uptake has also attempted to explain uptake characteristics in respect to social – economic factors (Muzari *et al.,* 2013). Demographic and institutional determinants have also been included in analyzing adoption of modern aquaculture and agricultural technologies (Lavison, 2013). A lot of work has been carried out in categorizing these determinants and many other authors classify these factors into different categories (Uaiene *et al.,* 2009).

2.2.3 Institutional factors

According to Mignouna *et al.,* (2011) joining a social group improves social capital status, information sharing and ideas. Group members learn from each other the advantages and usage of a new innovation. Uaiene *et al*. (2009) proposes that social networking is critical for individual decisions, and that, in the context of farming technologies, farmers share experiences and information among themselves.

According to Katungi and Akankwasa, (2010) on the effect of community based organization in adoption of corn-paired banana innovation in Uganda, farmers who participated more in such organizations were likely to engage in social learning about the innovation hence raising their chances of uptake of the technologies. Inspite of many researchers reporting a positive impact of social group on innovation uptake, social groups may also exhibit a negative influence on innovations uptake especially where there is free-riding behavior.

According to Foster and Rosenzweig, (2010) on uptake of green revolution innovations in India by farmers, acquainting themselves with externalities within social groups and networks increases the benefits of uptake, but farmers as well appear to be freeriding on their neighbours expensive experimentation with the new innovation. Bandiera and Rasul, (2010) as cited by (Hogset, 2005) propose that, learning externalities create opposite impacts, such that the more people involve themselves with experimentation of new innovations, the more advantageous it is to join, but also the more paying it is to free-ride on the experimentation of others.

Bandiera and Rasul, (2010) propose an inverted U-shaped individual adoption curve due to these contradicting impacts, implying that network impacts are positive at low rates of uptake, but negative at high rates of uptake of the new technologies. Gathering of information about a new innovation is another key variable that influences uptake of innovations (Shah, 2012). This increases farmers 'awareness of the technology as well as the efficient utilization of the innovation thus facilitating its uptake. Farmers always accept the innovation they are familiar with or have heard about (Andrew and Mark, 2013).

Mostly farmers are informed about the existence as well as the efficient use and benefits of innovations through extension staff (Solomon, 2008). Extension staff act as a link between the researchers of the innovation and users of the new technologies. This immensely reduces transaction costs of disseminating the information on the new technologies to a large non – homogenous population of farmers (Genius *et al*., 2010).

Extension staff mostly target certain farmers who are considered peers (farmers with whom a specific farmer interacts) creating an indirect or direct impact on the whole population of farmers in their respective localities (Genius *et al*., 2010). Many authors have reported a positive relationship between extension service delivery and technologies uptake. It's utterly important to ensure the information is accurate, reliable and consistent. Farmers ought to know the existence of innovation, its benefits and its utilization for them to adopt it. Bonabana (2007) reports that, access to technical extension service has also been considered to be a key factor in innovation adoption. Extension staff attempt as much as possible to understand the group dynamics of a particular group in relation to gender and their common interests (Akudugu *et al.* 2012). Farmers with common interests and same level of understanding usually tend to make choices of related modern technologies increasing likelihood of uptake of the technologies (Lavison, 2013) and (Onu, 2006).

Mignouna *et al*. (2011) reports that adoption of Imazapyr-Resistant Maize Technologies is a very good exampe; Factors determining innovation adoption (Kariyasa and Dewi, 2011); (Uaiene *et al*., 2009); Uptake of modern and improved maize and land technologies in Uganda by (Sserunkuuma, 2005); Uptake of new agricultural technologies in Ghana (Akudugu *et al.* 2012), among many. This is due to the fact that sensitizing farmers to information based upon innovation-diffusion theory is expected to stimulate adoption (Uaiene *et al*., 2009).

Information dissemination by extension staff reduces the negative effect of lack of years of formal education by in the overall decision to adopt some technologies (Bonabana, 2007; Yaron, and Voet, 2012). Provision of credit facilities has been reported to increase technology uptake (Mohamed and Temu, 2008). Access to credit promotes and stimulates the adoption of risky innovations through relaxation of the liquidity challenges as well as boosting of household's-risk bearing ability (Simtowe and Zeller, 2006). They report that, with an option of borrowing, a household can get rid of low risk but inefficient income diversification strategies and concentrate on effective investments which are more risky but stable (Simtowe and Zeller, 2006).

Access to credit facilities has however been found to be gender biased in some countries with female-headed households being discriminated against by credit institutions, and thus are unable to finance yield-raising innovations, leading to low uptake rates (Muzari *et al.*, 2013). Simtowe and Zeller, (2006) and Mkandawire, (2013) report that, there is thus need for policy makers to improve current smallholder credit facilities to ensure that a bigger number of smallholders are able to access credit, more specifically female-headed households. According to Muzari *et al.*, (2013), this may necessitate crafting of credit packages that are suited to address the needs of specific target groups. A good example is in Kenya where the government has initiated a program that offers free interest loans to youth and women through UWEZO fund (Muzari *et al.*, (2013). Another key determinant of a new technology uptake by farmers is therefore gender considerations to enhance women and youth empowerment increasing their net benefits (Foster and Rosenzweig, 2010).

2.2.4 Household-specific factors

Human capital of a farmer is assumed to have a significant influence on farmers' decision to adopt new innovations (Diego and Bart, 2008). Many studies on adoption have attempted to measure human capital through the farmer's household size, age, education, gender, and marital status (Keelan *et al.*, 2014; Mignouna *et al.,* 2011;

Fernandez and Daberkow, 2006). Education level of the farmer is assumed to have a positive influence on farmers' decision on whether or not to adopt new technologies.

Level of education of a farmer improves his/her ability to acquire process and utilize information relevant to uptake of a new technology (Namara *et al*., 2013; Lavison 2013). According to studies conducted by Okunlola *et al.* (2011) on adoption of new technologies by fish farmers in Nigeria and (Ahmed, 2009) on adoption of organic fertilizers, they found that the level of education of a farmer had a positive and significant influence on uptake of the technologies. Waller *et al*., (2008) reports that this is because higher education determines respondents' thoughts and attitudes making them more rational, open and able to analyze the net gains of the new innovations.

This eases the introduction of new technologies which eventually affect the uptake process (Adebiyi and Okunlola, 2010). Uematsu and Mishra, (2010) note that, several studies that have reported a positive relationship between adoption and education include; (Goodwin and Mishra, 2006) on forward pricing methods, (Huffman and Mercier, 2009); (Putler and Zilberman, 2008) on uptake of microcomputers in agriculture. Mishra and Park (2005); Mishra *et al.*, (2009) on utilization of internet, (Rahm and Huffman 2009) on minimal tillage, Roberts *et al.*, (2014) on specialized farming and Traore *et al*., (2010) on on-farm trials uptake of conservation tillage. Other studies have reported minimal or negative influence of education on the rate of technology uptake (Khanna, 2011; Grieshop *et al*., 2008; Bandiera and Rasul, 2010; Banerjee *et al*., 2008; Samiee *et al*., 2009). Studies on the effect of education on technology adoption by (Uematsu and Mishra 2010) reported a negative influence of formal education towards adopting genetically modified crops. Age is additionally assumed to be a key determinant of uptake of new technologies, measured in the number of years (Roberts *et al.,* 2014).

More often than not older farmers are assumed to have undergone extensive and numerous training during their farming experiences in different areas of aquaculture or agricultural trainings (Koppel, 2009). Information and exchange of ideas among older farmers increases adoption (Lavison, 2013). Older farmers have gained wider knowledge, ideas and experiences over a long period of time and are better placed to evaluate innovation information than youthful farmers (Dewi and Kariyasa, 2011; Mignouna *et al.,* 2011). Mauceri *et al.,* (2005) on the contrary report a negative relationship between age and uptake of technologies. This relationship is explained by Adebiyi and Okunlola, (2010) that as farmers age, risk aversion increases and interest in long term investment in the farm decreases.

Youthful farmers are more willing to try new technologies since they are typically less risk-averse. According to Alexander and Van, (2015) uptake of genetically modified modern maize increased in youthful farmers as they acquire experiences and improve their stock of human capital but decreased with age for those farmers about to retire. Gender aspects in new agricultural technologies uptake have been examined for a long period of time and many studies have cited mixed evidence concerning the different roles women and men play in innovation uptake (Bonabana, 2007).

Morris and Doss, (2009) found no significant relationship between gender and chances of a farmer to adopt improved modern agricultural maize technologies by farmers in farms in Ghana. They recommend that, technologies uptake decisions depend solely on access to resources, and if in a specific context men are likely to have better access to such resources than women, then in that particular context the innovations will not equally benefit men and women (Bonabana 2007). In certain instances gender may have a significant impact on some innovations. Gender influences technologies uptake because the head of the homestead is the key decision maker and men have more access to and control over critical production endowments than women due to socio-cultural norms and values (Omonona *et al.,* 2006; Mignouna *et al*., 2011; Mesfin, 2007).

According to Obisesan, (2014), gender had a significant and positive impact on uptake of modern improved cassava production in Nigeria. His results are similar to those of (Lavison 2013) who concluded that men were more likely to adopt organic fertilizer compared to women. Size of household is utilized as a measure of availability of labour. It is a determinant of adoption process because a larger household has the capacity to relax the labour constraints during introduction of new technologies (Bonabana, 2007; Mignouna *et al.,* 2011).

2.2.5 Knowledge gaps

Abdoulaye *et al*., (2013) investigated growth performance of monosex tilapia fingerlings in a recirculation system only, while (Okonji *et al.,* 2013) tested performance of the monosex *Oreochromis niloticus* fingerlings in concrete ponds. Other culture systems for example earthen and liner ponds were not tested. Workagegn *et al,* (2014) and Rad *et al.,* (2013) tested growth performance of juvenile *Oreochromis niloticus* monosex tilapia using commercially formulated feeds. Effect of fertilizer and lime were not tested.

Bush and Marschke, (2014) argue that, current approaches used to understand and support aquaculture technologies, display gaps regarding the absence of multi-level and multi-disciplinary approaches. They reported that the knowledge gaps in aquaculture technologies include; inadequate consideration of the environmental dimension, limited in-depth analysis at producer level on the linkages between aquaculture technologies and ecological systems. The study will therefore attempt to address the knowledge gaps identified, contributing to wealth of knowledge in scientific research and for planning purposes.

Mostly farmers are informed about the existence as well as the efficient use and benefits of innovations through extension staff (Solomon, 2008). Extension staff act as a link between the researchers of the innovation and users of the new technologies. This immensely reduces transaction costs of disseminating the information on the new technologies to a large non – homogenous population of farmers (Genius *et al*., 2010). Extension staff mostly target certain farmers who are considered peers (farmers with whom a specific farmer interacts) creating an indirect or direct impact on the whole population of farmers in their respective localities (Genius *et al*., 2010). Studies on extension service have concentrated on other enterprises and not aquaculture. Study on effect of extension service on adoption of aquaculture technologies is therefore necessary to bridge the gaps.

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter describes the location of the study area, climatic, demographic and ecological conditions. Pond design, construction of the ponds and stocking are also described. The methodology for each specific objective is given, finally sampling method, data collection and analytical procedures employed during the study.

3.1 Study area

3.1.1 Location of the study area

The study was carried out in Imenti North Constituency in Meru County which is on the eastern side of Mt Kenya, straddling the equator within 0^o 6' North and about 0^o 1' South, and latitudes 37^o West and 38^o East. The county has a total area of 6,936.2 km^2 out of which 1,776.1 km^2 is gazzetted forest (CIDP, 2014). The county boarders Isiolo to the North, Laikipia to North West, Tharaka Nithi to the South and Embu County to South West. The county is about 232 km North East of Nairobi County (Figure 3.1).

3.1.2 Climate/relief

The climate of the area is influenced by altitude. Altitude ranges from 300m to 5,199m above sea level (CIDP, 2014). Rainfall ranges from 300 mm per annum in the lower altitude areas, to 2500 mm per annum in the higher altitudes. June is the driest month with 11mm of rain while the highest precipitation of 1602mm comes in November. Other areas receive an average of 1250 mm of rainfall annually. Rainfall is bimodal with long rains occurring from mid-March to May and short rains from October to December. Temperatures range from a low of 8 ^oC to a high of 32 ^oC during the cold and hot seasons respectively. June and September are the hottest months while, July is the coldest month (CIDP, 2014).

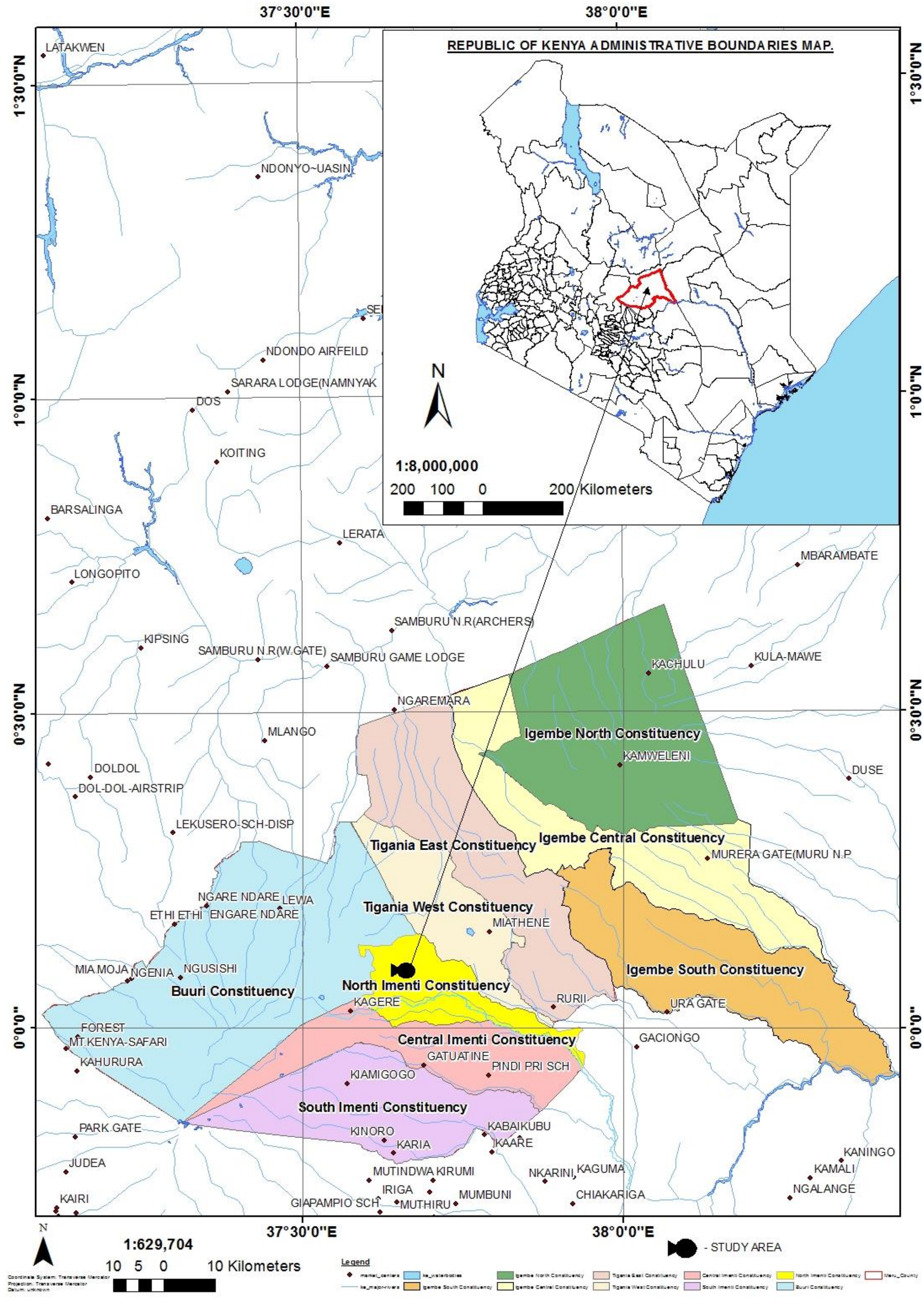


Figure 3.1 Map of Meru County, showing Imenti North Constituency where the study ponds were established, 0”05’ 0”N and 37”65’0”E (Source; Meru CIDP-2014).

3.1.3 Drainage and soils

The drainage pattern in the county is characterized by 13 permanent rivers and streams originating from the catchment areas of Mt Kenya and Nyambene ranges in the North. Kathita, Mutonga, Mariara, Kinyaritha, Rugusu, Kongoacheke, Ngare Ndare are the main rivers found in the county. Notable dams are Kithithina, Ngusishi, Ontulili, Rurii and Timau. Nkunga which is a sacred Lake has many big tilapia fish. The lake also has immense potential for ecotourism activities. The rivers and streams form the main source of water for domestic, aquaculture and agricultural use (CIDP, 2014). Several types of soils are found in the county among them, deep red loam soils, clay and sandy soils among many (KBS, 2012).

3.1.4 Population

The county's population growth rate is estimated at 2.1 per cent per annum. According to 2019 population census, the county has a population of 1.546 million people with a population density of 6 people per square kilometre (KBS, 2019). The county population is projected to be 1,775,511 in 2022. The average land holding size is 1.8 ha for small scale land owners and 18.25 ha for large scale owners (KBS, 2019).

3.1.5 Economic activities in the area

Agriculture is the main economic activity carried out in Meru County, it comprises of large and small scale farming. The food crops grown in the county are maize, pulses, bananas, sorghum, millet, yams and cassava (CIDP, 2014). Livestock reared are cattle (dairy and beef), sheep, rabbits, chicken and goats. Fish farming practiced in the study area involves rearing of fish in controlled environment (earthen, liner, concrete or raised ponds). The pond water is usually fertilized using DAP inorganic fertilizers. The water is also sometimes limed and fish are fed using commercial fish pellets procured from feed stores in the county. The fish cultured is tilapia, common carp, clarias, trout and ornamental fish. Extension service in the area is provided by fisheries personnel employed by the county. The county is suitable for both cold and warm water fish culture, (CIDP, 2014). The county produces about 162 tonnes of fish annually (CIDP, 2014). Fish market chain once the fish is harvested involves selling fish at the farm gate or fish is transported in cooler boxes and sold in market outlets in towns or institutions like schools (Opiyo *et al.,* 2014).

3.2 Research design

3.2.1 Selection of the culture systems

The actual study was preceded by a preliminary survey between July 2015 and August 2015 in Meru County. The aim of the preliminary study was to; (a) identify the most commonly used culture systems by farmers and (b) collect information on the regularly used inputs in the ponds. The preliminary survey identified three (3) most common types of culture systems used by the fish farmers in the field, liner, earthen and concrete ponds (most of the farmers were using liner ponds, about 70 %, 20 % concrete and earthen 10 %. There are about 2040 fish farmers in the study area. The most used inputs were, Diammonium phosphate, inorganic fertilizer, commercial fish pellets (feeds), lime and organic animal manure. Culture systems selected were liner, earthen and concrete as they were the most common culture systems used by the fish farmers. The inputs selected for this study were fish pellets, Diammonium phosphate and lime.

3.2.2 Study design and preparation of the culture ponds

A randomized block design was set up. Fourty eight (48) outdoor fish ponds, each 2 square metres with a depth of 1 metre, were constructed at the study site (Figure 3.2). The first sixteen earthen ponds were excavated followed by scooping of soil, then the floor and dykes were levelled, this was to ensure the ponds filled completely with water including the shallow end. The second sixteen ponds were excavated, levelled and finally lined with a Ultra-Violet treated polythene material able to stand solar radiation. The final set of sixteen ponds required specialized masonry labour since it required to be constructed using building stones, sand, cement and ballast. A netting material was placed at the bottom of each pond and secured around the pond using 4 stick pegs before stocking to ease removal of fish. After construction of the ponds, the area was secured using strong wire mesh to keep away predators and ensure the ponds were not interfered with by stray animals or passersby. A total of 36 treatment ponds and 12 control ponds were used hence a total of 48 ponds (Figure 3.3).

Control ponds; in each treatment there was one control pond. In the control pond, nothing was added to the pond water after stocking each pond with 8 tilapia fingerlings of approximately 20 g. Total number of control ponds used was therefore twelve (12).

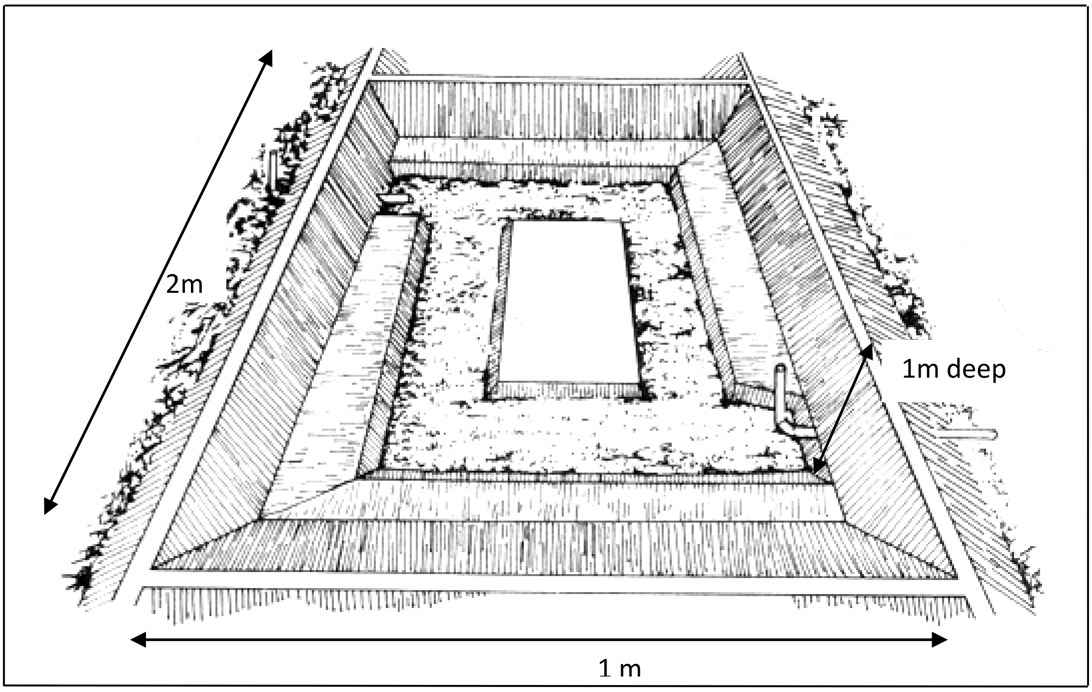


Figure 3.2: Bottom design for the fish ponds (Source Pinji, 2013)

3.3 Preparation of the fish ponds and treatment

All the fish ponds were filled with water. The source of water for filling the ponds was spring water located at the study site. A set of 9 ponds (3 concrete, 3 liner, 3 earthen) of each culture system were treated with 2 gms, 4 gms and 6 gms of fish pellets, (Figure 3.3). Second set of 9 ponds (3 of each) were treated with 2 gms, 4 gms and 6 gms of DAP, third 9 (3 of each) were treated with 2 gms, 4 gms and 6 gms lime and the last nine (3 of each system) were treated with a combination of (2 gms of feed, DAP and lime), 4 gms feed, DAP and lime and 6 gms feed , 6 gms DAP and 6 gms lime) or 12 gms of each input and left for 2 weeks before stocking (Figure 3.3).

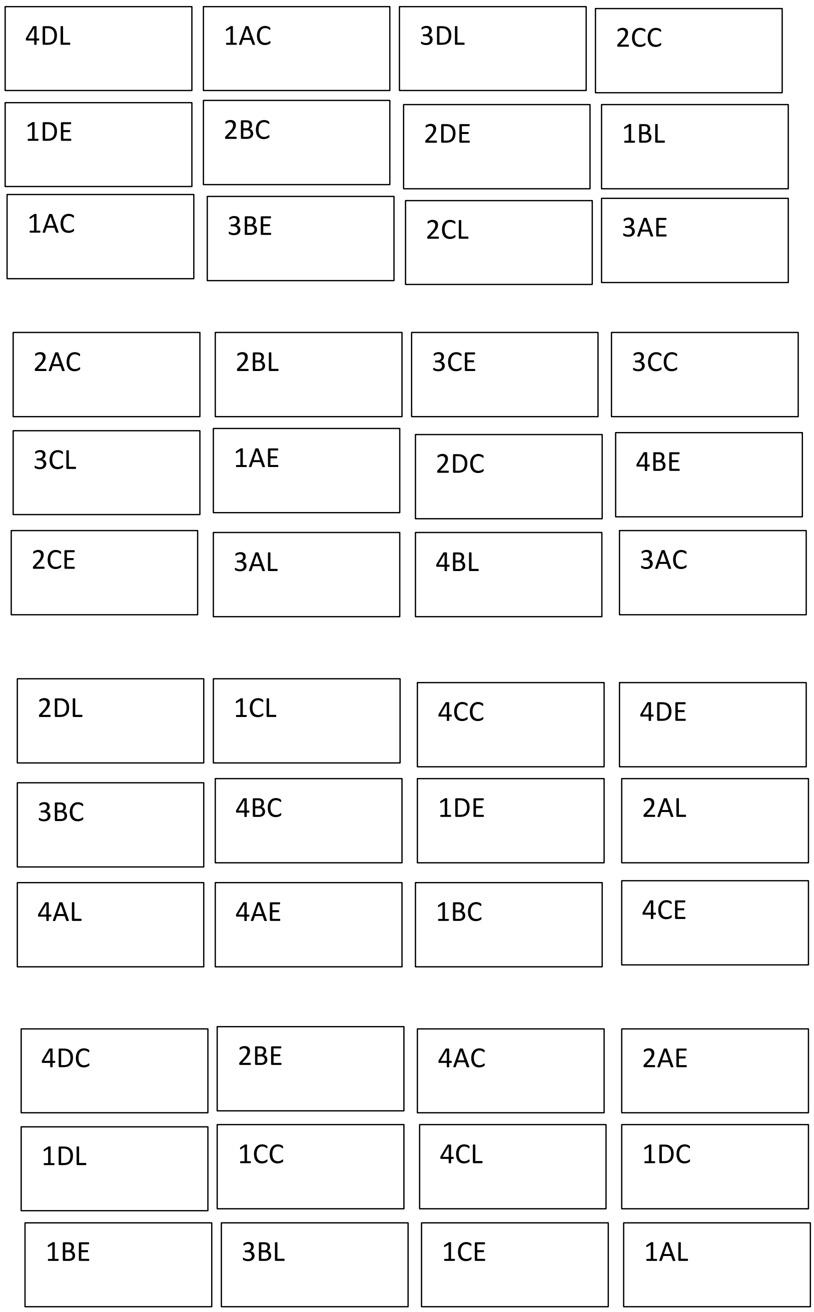
The study site was divided into four blocks separated by 1m path used for walking through during the experimental measurements (Figure 3.3). Each block for each objective in the study. The treatments were carried out in the individual labelled ponds as illustrated in (Table 3.1) as per the four objectives (treatments).

3.3.1 Stocking of the fish pond

O*reochromis niloticus* fingerlings were randomly selected from Vision Fish Hatchery in the county and kept in plastic holding tanks, for two weeks to acclimatize (Opiyo *et al.,* 2014). Using a scoop net, the fish were slowly removed from the holding plastic tanks and weighed using a digital weighing balance before stocking into the study ponds. Fingerlings of approximately 20 grams were used. The stocking density was 4 fish per square metre (Anum *et al.,* 2013; Dior *et al*., 2013).

3.4 Field analytical procedures

3.4.1 Temperature (°C)



KEY

-1AE, 1BE, 1CE, 1DE – Earthen ponds. One control per culture system

-1AL, 1BL, 1CL, 1DL – Liner ponds. -1AC, 1BC, 1CC, 1DC – Concrete

Figure 3.3: Randomized block design of the fish ponds

Table 3.1: Treatments of the various culture system ponds

Treatment	Fish pellets	Liner	Earthen	Concrete	Control
1A	2 gms pellets fed at 10 am and 4pm	1AL….	1AE…	1AC….	1C1…
1B	4 gms pellets fed at 10 am and 4pm	1BL….	1BE…	1BC….	1C2...
1C	6 gms pellets fed at 10 am and 4pm	1CL….	1CE…	1CC….	1C3…
	DAP Treatment				
2A	2 gms DAP, 2 gms feeds	2AL….	2AE…	2AC….	2C1….
2B	4 gms DAP, 4 gms feeds	2BL…..	2BE…	2BC….	2C2…
2C	6 gms DAP, 6 gms feeds	2CL…..	2CE…	2CC….	2C3…
	Lime treatment				
3A	2 gms Lime, 2 gms feeds	3AL…	3AE…	3AC….	3C1…
3B	4 gms Lime, 4 gms feeds	3BL…	3BE…	3BC….	3C2…
3C	6 gms Lime, 6 gms feeds	3CL…	3CE…	3CC….	3C3…
	DAP, Lime and Pellets combination				
4A	2 gms DAP, 2 gms pellets 2 gms Lime	4AL…	4AE…	4AC….	4C1…
4B	4 gms DAP, 4 gms pellets,4 gms Lime	4BL….	4BE…	4BC….	4C2….
4C	6 gms DAP, 6 gms pellets,6 gms Lime	4CL….	4CE…	4CC….	4C3….

Water temperature in each pond was measured using a temperature sensor of the pH probe (Type Sen Tix 41 – 3) of a multiline meter (WTW, Weilheim-Germany). The probe was immersed in water to a depth of 30 cm allowed to stabilize and the readings recorded in degrees Celsius. Temperature readings of each pond were taken every day, at 10.00 am and 4.00 pm just before feeding the fish.

3.4.2 pH

Water pH readings were taken every day during the study period, twice a day at 10.00 am and 4.00 pm just before feeding using a pH probe meter (Type Sen Tix 41 – 3) of a multiline meter (WTW, Germany). The probe was immersed to a depth of 30 cm and readings taken after it stabilized.

3.4.3 Dissolved oxygen (mg L^{-1})

Dissolved oxygen level was measured using an oxygen probe (Type Cello X 325) WTW, Germany with temperature compensation up to 25 ^{o}C. The probe was immersed in water to a depth of 30 cm and water was stirred with the probe, allowed to stabilize and the readings taken.

3.4.4 Weight measurement

Weighing of the fish was done at 30, 60 and 90 days after the start of the experiment using a digital weighing balance, which had a weighing bowl. The fish was fished using a scoop net, and then placed on the weighing balance and the weight recorded to the nearest two decimal points in grams. After weighing, the fish was returned into the water to avoid stressing or killing the fish. Fish is usually sold by weight in the market and weight was considered to be proportional to length in the study (Ngugi, 2013).

3.4.5 The factors that influence adoption of fish farming.

3.4.5.1 Determining sample size and sampling procedure

The factors influencing the adoption of fish farming technologies all male tilapia, liner, concrete, earthen and intensive and fish production, were determined using interviews.

From 2040 fish farmers who were supported through ESP (Economic Stimulus Project) in the study area (Kirimi, 2016), 180 respondents were selected for interviewing. The sample size of 180 respondents was calculated using Charan and Biwas, (2013) formula where,

Sample size = Z^2 P (1 – P)/d^2

Z^2 - Is standard normal variate (at 5 % type one error). In several studies, P values are considered significant below 0.05 hence 1.96 is used in the formula.

P = Proportion of the population in the study area engaged in active aquaculture = 2040 or 0.136 % of 1.5m

D – Absolute error or precision – 0.05

Substituting 1.96 X 1.96 X 0.136(1 - 0.136)/$.05^2$

=180 Farmers

3.4.5.2 Selection of the respondents

Meru County has 9 Sub counties and the distribution of the fish farmers is not the same in the 9 Sub-Counties (table, 3.2). Selection of the respondents was done randomly. The number of fish farmers in each Sub County was coded and a sampling frame developed. Names of respondents to be interviewed was then selected randomly using a computer software, Kutools for Excel (Detong, 2017).

3.4.5.3 Data collection procedure

Data on factors which influence adoption was collected using a questionnaire, with the help of County deputy fisheries officer, 9 subcounty fisheries officers and 9 clerks who were trained on how to fill the questionnaire. Each subcounty fisheries officer was issued with the desired number of semi – structured questionnaires which were then self-administered in the field. Field visits to distribute and interview the respondents was conducted using motorbikes by the officers and clerks. The interview was precluded by introduction and then answering of the questions by interviewees asked by the interviewer who recorded answers on the questionnaire in the field. A total of 180 questionnaires were used.

Table 3.2 Population and sampling frame for the study

Subcounty	**Population**	**Sample**
Imenti South	318	28
Imenti Central	210	18
Imenti North	282	26
Buuri	117	10
Tigania West	293	26
Tigania East	296	26
Igembe Central	165	14
Igembe North	110	10
Igembe South	249	22
Total	2040	180

Ethical considerations; that privacy, confidentiality, principle of informed consent and protection of the rights of the vulnerable in the community were upheld. It was also envisaged that the researcher would confine the interview to the scope of the research only, utilizing his skills effectively and ethically. Further it was expected also that the respondents consented to the interview voluntarily without coercion or any form of inducement.

3.4.5.4 Level of adoption and factors influencing adoption

Factors that influence adoption of fish farming were investigated using logistic regression (Hardwick *et al.,* 2015) and (Hilbe, 2009). Level of adoption of aquaculture technologies was computed using marginal effects, margins dy/dx at means (Richard, 2017). Implying that any unit increase in any value of the independent valuables (access to markets, credit facilities, extension services, farm size and all other socio-economic characteristics) the dependent valuable (adoption of aquaculture technologies) would also increases by one unit (Hosmer, 2013). Then the factors are ranked according to their importance (from the one with the highest value to the lowest).

The dependent variable, adoption of fish farming was dichotomized with a value of 1 if a farmer was an adopter of fish farming and 0 if not an adopter (Thangata, 2003). The independent variables included, age of household head, gender of household head, marital status of household head, years of education, size of household, land size, annual farm income, market availability (measured by considering number of fish outlets or markets), credit availability, labour availability and extension services availability (Table 3.3).

Age of household head (AGH) was included in the model as a continuous variable measured in years. It was included in the model because age influences the adoption of new technologies. While young people may want to test technologies, they do not have many resources while old people may have resources, which can help them adopt fish farming. Age was therefore, hypothesized to be positively related to the adoption of fish farming.

Sex/Gender of household head (GHH) was included in the model as a dummy variable with 1 for male and 0 for female to examine if sex of the household head had any influence in the adoption of fish farming. It was expected that the majority of adopters of fish farming would be males perhaps because men mostly carry out construction of ponds while women do other tasks such as pond management. It was therefore hypothesized that gender would have a positive relationship to the adoption of fish farming technologies**.**

Marital status (MS) of the household head was included in the model as a dummy variable with 1 for those people who were married and 0 representing those who were not married. Most married people are considered to be influential, have access and control of resources such as land, livestock etc. It was thus hypothesized that adoption of fish farming was positively related to marital status of the household head.

Years of educational (YOE) was categorized as a continuous variable with primary level, secondary level, college, university level and others captured as the highest level of education in years attained. Exposure of household head to some education was considered to have influence on understanding new technologies. Farmers with some education are able to process information and are open to new ideas. Educational status was therefore considered to have positive influence on adoption decisions.

Number of dependents in a household, family size (SOH) was recorded as a continuous variable. Adoption of fish farming is expected to be positively related to family size. Farmers with large family are likely to adopt fish farming. They are expected to have enough labour compared to those with small family size.

Land size (LS) was recorded in hectares. It included all land available to the household. The larger the size of the land, the higher the chances that one would adopt fish farming. Land size was therefore hypothesized to have a positive relationship to adoption of fish farming.

Annual farm income (AFARMI) was included as a continuous variable measured in Ksh per year. Availability of farm income (capital) increases the financial capacity of the farmer to venture into various capital intensive projects. Amount of farm income was therefore hypothesized to have a positive relationship with adoption of fish farming technologies in the study area.

Table 3.3: Description of the variables used in the model

Variable	Description	Coding
AGH	Age of household head	Continuous variable measured in years
GHH	Gender of household head	Dummy variable with 1 for male, 0 for female
MS	Marital status	Dummy variable with 1 for married, 0 not married
YOE	Years of education	Continuous variable measured in years of schooling
SOH	Size of the household	Continuous variable measured in number of people in a household
LS	Land size	Continuous variable measured in number of acres
AFARMI	Annual farm income	Continuous variable measured in Ksh
MAV	Market access	Dummy variable with 1 for yes and 0 none
CREA	Credit access	Dummy variable with 1 for yes and 0 none
LA	Labour availability	Continuous variable measured in number of labourers
ES	Extension service	Dummy variable with 1 for yes and 0 for no
INTE	Intensive	Dummy variable with 1 for yes and 0 for no
EXTE	Extensive	Dummy variable with 1 for yes and 0 for no
LIN	Liner	Dummy variable with 1 for yes and 0 for no
CONC	Concrete	Dummy variable with 1 for yes and 0 for no
EART	Earthen	Dummy variable with 1 for yes and 0 for no
AMT	All male Tilapia	Dummy variable with 1 for yes and 0 for no

Access to market (MAV) was recorded in the model as a dummy variable with 1 for availability of market and 0 otherwise. This was measured by recording the number of market outlets in the area. Availability of produce market was expected to influence adoption of fish farming technologies greatly as it acts as a catalyst to fish farming. It was therefore hypothesized that availability of a fish market would have a positive relationship to adoption of fish farming in the study area.

Access to credit facilities (CREA) was included as a dummy variable with 1 for access to credit facilities and 0 otherwise. Provision of credit facilities was expected to enhance financial capacity of fish farmers. Access to credit facilities was therefore hypothesized to have a positive relationship to adoption of fish farming technologies.

Labour availability (LA) was included in the model as a continuous variable measured in the number of labourers in a household. Labour availability eases the farmers' burden especially during fish pond construction, stocking, fish pond management, harvesting and marketing. Labour availability was thus hypothesized to have a positive relationship with adoption of aquaculture technologies in the study area.

Extension services (ES) was recorded as a dummy variable with I if farmer has access to extension contact and 0 if the farmer has no extension contact. Uptake of new technologies is influenced by contact between extension staff and farmers due to information flow. It was hypothesized that quality extension contact is positively related to adoption of fish farming. The parameters in the model were estimated using the following equation (Hardwick *et al.,* 2015):

$$E(Yi) = \alpha + \beta_1 AGH + \beta_2 GHH + \beta_3 MS + \beta_4 YOE + \beta_5 SOH + \beta_6 LS +$$
$$B_7 AFARMI + \beta_8 MAV + B_9 CREA + \beta_{10} LA + \beta_{11} ES + \mathcal{E}_i$$

Where Yi = dependent variable (adoption); α = constant; β_i = coefficients of each of the independent variables; $\mathcal{E}_i$ - error term.

Computation of the level of adoption resulting from every unit change in the value of each of the independent variables considered was conducted by computing the marginal effects of the logistic regression model using the formula margins,dydx(*) atmeans (Richard, 2017). Ranking of the factors was then carried out according to their importance. The factor with the highest marginal effect value was ranked as having the strongest influence while the one with the lowest marginal effect value was ranked as having the least influence compared to the other factors (Howell, 2010).

3.4.6 Data analysis

The primary raw data from the field was first keyed in excel sheets for exploration, cleaning and coding. Non numerical data was assigned numerical values for easier coding of the various parameters. The data was then organized for subjecting to the analysis tool.

Analysis of Variance (ANOVA) was used to find out the significant differences in the mean weight of fish and various physico-chemical parameters among the culture systems under various treatments (objective 1 to 3). The Logistic regression analysis was used to examine the factors that influence adoption of fish farming technology (objective 4). Differences among means were tested using Turkey's (HSD) separation method and significance was at 95 % confidence interval. Turkey's method of separation of means was chosen due to its high accuracy compared to the others and good output tables which are easy to interpret. Data were presented using tables, Bhistograms and graphs.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

The chapter presents findings on the effects of varying fish pellets, DAP fertilizer, lime and a combination of the three inputs on O*reochromis niloticus* growth performance in three different culture production units. Comparison of growth performance of the tilapia in different culture production systems under the different treatment is presented. Further, findings on the factors influencing the level of adoption of fish farming by fish farmers are also presented.

4.2 Physico – chemical parameters of the three culture systems (Earthen, Liner and Concrete)

4.2.1 Temperature (°C)

Temperature readings showed modest variation among the three culture systems during the study period (Table 4.1). The temperature ranged from 23.81 to 26.81 degrees Celsius in liner ponds, in earthen ponds the temperature ranged from 24.64 to 25.35 degrees Celsius while in the concrete ponds the temperature ranged from 19.54 to 23.51 degrees Celsius (Figure 4.1). The highest mean temperature of 25.72 degrees Celsius was recorded in the liner pond while the lowest 19.54 degrees Celsius was in concrete ponds, (Table 4.1). Temperature increased steadily initially in all the culture systems with liner pond temperatures being higher than the others upto day 60, after which temperatures in earthen pond continued increasing while those in liner and concrete ponds decreased upto to the end of the study period (Figure 4.1).

Using one way Analysis of Variance, the mean temperatures in the three culture systems were significantly different (p<0.0001, df =2). Mean separation using Turkey's test revealed that mean temperatures in liner ponds were significantly higher than the mean temperatures in concrete culture system F=436.64 p=0.0001, df = 2, (table 4.1).

Table 4.1: Mean temperature, pH and dissolved oxygen values recorded in the three culture systems between August 2015 and November 2015,

Parameters	Liner	Earthen	Concrete
Temperature (°C)	25.72 ± 0.297^{a}	25.11 ± 0.152^{a}	21.85 ± 0.300^{b}
pH	8.35 ± 0.114^{a}	8.04 ± 0.091^{a}	9.47 ± 0.170^{b}
Dissolved Oxygen (mg l^{-1})	5.21 ± 0.322^{a}	4.15 ± 0.143^{ab}	6.74 ± 1.119^{b}
			p = 0.0001

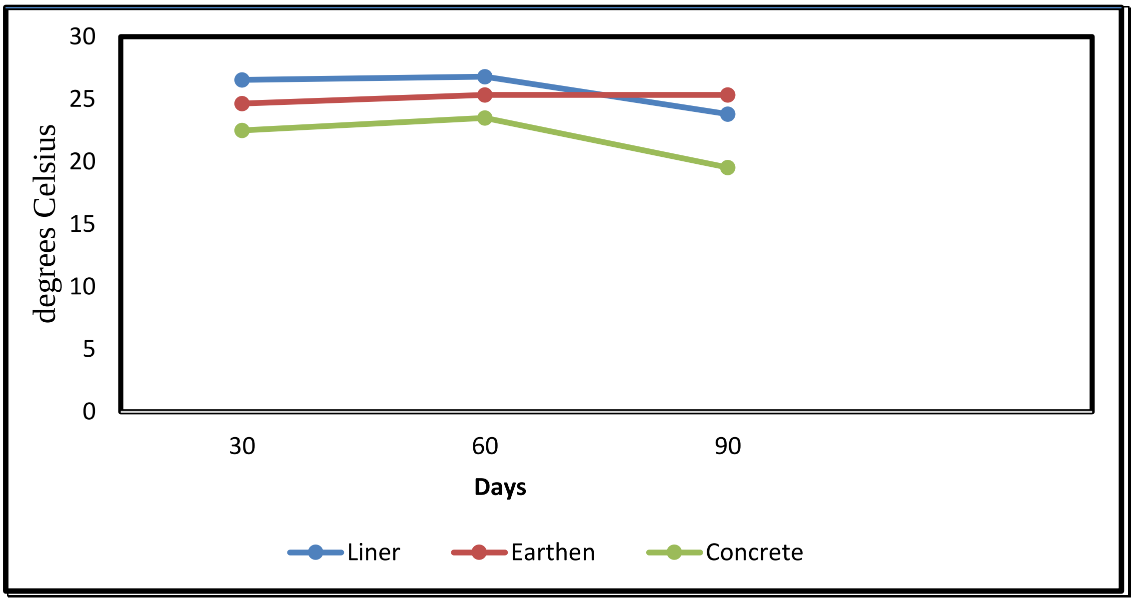


Figure 4.1: Mean monthly temperatures in degrees Celsius recorded in the three culture systems during the study period (August 2015 to November 2015).

Water temperature is an important determinant of many biological processes. Change in temperature in water ponds is brought about by differences in ambient temperature, presence of vegetation cover and shade (Ali *et al.*, 2013, Kitur *et al.*, 2009). According to Ryan, (2017) seasonal changes in the atmospheric temperature influence surface water and bottom water body temperatures. Density difference between warm surface waters (the epilimnion) and cold bottom waters (the hypolimnion) increases to a point where the two layers do not mix. In the surface water, due to sunlight penetration there is more photosynthetic and respiration activity leading to release of more energy hence higher temperatures in the surface waters compared to the bottom water (Veeramani and Santhanam, 2015). Decomposition of organic matter in the pond can also lead to increase in temperature due to release of energy (Ryan, 2017).

Temperature of surface water body is also influenced by speed of wind, on a windy day the temperature of the surface water is lower compared to a non – windy day when temperature is higher (Noble, 2007). According to Paaijmans *et al.*, (2008) water turbidity also affects water temperature, as suspended particles in a water column absorb and scatter sunlight and hence determine the extent of solar radiation. The more suspended soil particles in a water body, the warmer the water body especially during daytime. Akunga *et al.*, (2018) report that, fluctuations of pond water temperature could be due to atmospheric variables namely; air temperature, wind direction and pond bottom.

The higher mean temperature in the liner pond could be attributed to the fact that liner pond is lined with a black polythene sheet which is a good absorber of heat while the low temperatures recorded in the concrete pond could be attributed to the fact that concrete is a poor conductor of heat and hence most of the heat is lost (Figure 4.1). Decomposition and respiration in the liner ponds due to higher temperature leads to production of more heat in the pond system thus increasing temperature compared to the other culture systems. In the three culture systems, temperatures increased steadily upto day 60, then there was a decline, this could be attributed to decomposition and respiration. After day 60, decomposition and respiration could have reduced and this could have slowed down energy production which led to the decline in temperatures in the culture systems. Decline in decomposition and respiration could have been faster in liner ponds due to high temperature as compared to earthen ponds and this led to more decline in temperature in the liner ponds compared to the earthen ponds after day 60 (Figure 4.1).

In the concrete ponds, temperatures were lower than in the other systems throughout the experiment due to the fact that concrete is not a good absorber of heat hence the low temperatures. There was also remarkable decline in temperature in the concrete ponds after day 60 compared to the other systems since the little energy in the concrete ponds got exhausted fast with reduced decomposition and respiration in the ponds. Due to the low temperature in concrete ponds, decomposition and respiration were also low hence low heat in the concrete.

The mean temperatures continued to rise steadily in the earthen culture system compared to the other culture systems after day 60. This could be attributed to the natural processes (algae and photosynthetic activity) in earthen pond system since earthen pond has a substrate (soil). The earthen system is therefore more stable and that is why the temperatures never went down abruptly as opposed to concrete and liner ponds which are mainly artificial in nature hence lost a lot of heat very quickly after the decomposition and respiration leading to the abrupt decline in temperatures (Figure 4.1).

Temperature range of 23.81 °C to 26.81 °C in liner pond (Figure 4.1) in the study is lower but within the same range with those of liner ponds in Egypt, 24.11 °C to 26.92 °C (Dagne, 2013). Temperatures in earthen ponds, 24.64 to 25.35 °C, were higher but within the same range with earthen ponds in Indonesia, 22.00 to 24.96 °C (Abdel, 2008). Concrete ponds had the lowest temperature range of 19.21 to 21.85 °C which is slightly higher but compares well with that reported by (Frida, 2014), 19.20 to 21.80 °C in Kabete, Nairobi Concrete ponds.

4.2.2 pH

The pH recorded throughout the study period showed modest variations (Figure 4.2). The mean pH ranged from 7.8 to 8.42 in earthen ponds, 9.2 to 9.8 in concrete and 8.10 to 8.5 in liner culture systems (Figure 4.2). The highest mean pH of 9.47 was recorded in concrete ponds while the lowest, 8.04 was in earthen culture system (Table 4.1). Throughout the study period, pH was consistently high in concrete ponds as compared to the other culture systems (Figure 4.2). The pH of concrete and liner ponds declined after 60 days while in the earthen pond, it increased slightly after day 60 (Figure 4.2). Using one way Analysis of Variance, pH readings in the three culture systems were significantly different (p<0.0001, df = 2). After separation of means using Turkey's test, it was revealed that mean pH in concrete ponds was higher than in earthen and liner ponds (Table 4.1).

Changes in pH under natural conditions is controlled by the concentration of carbon dioxide, carbonate and bicarbonate ions (Kitur *et al.,* 2009). In an aquatic ecosystem, pH is determined by the balance between photosynthesis, respiration and decomposition. The spatial and temporal changes in photosynthesis and respiration combined with the buffered state of water determine the pH range experienced in a water body, (Kitur *et al.,* 2009), pH of 6 to 9 is considered desirable for most freshwater fish. Water in ponds reflects the quality of the soils in which they are located (Andy *et al.,* 2015, Udo, 2007). In acid soils, ponds typically have low pH. Fish production in waters of pH less 6 is poor. Calcite (calcium carbonate) and dolomite (a combination of calcium and magnesium carbonates) both increase the total hardness (the calcium and magnesium concentration) and the total alkalinity (the carbonate and bicarbonate concentration) of water (Andy *et al.*, 2015).

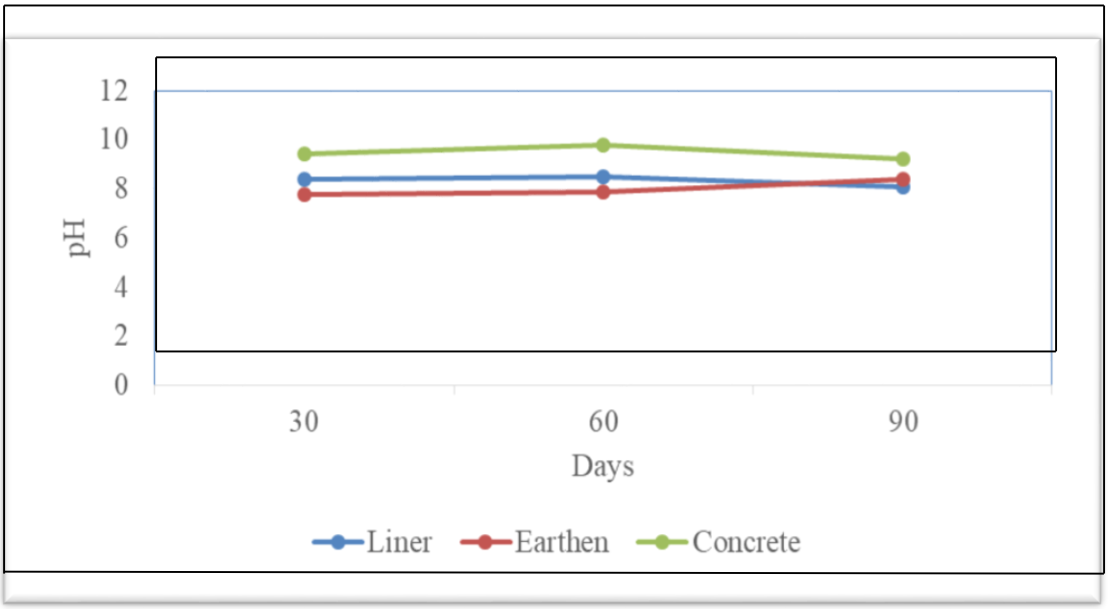


Figure 4.2: Monthly mean pH values recorded in the culture systems during the study period (August 2015 to November 2015).

According to El –Sherif and El – Feky, (2009), pH below 6 and above 10, fish performance is greatly impaired due to poor multiplication of microorganisms at very low and high pH which reduces live feeds for the fish in water. According to Kirimi, (2016), a pH range of 8.93 to 10.62 is best for optimal fish growth performance in ponds in Kenya. Zooplanktons and phytoplankton activity is enhanced at this pH range (8.93 – 10.62) and above or below which fish growth is grossly affected.

Water in the earthen ponds is in direct contact with the soils which could contribute to the low pH recordings in the earthen ponds (Table 4.1) possibly due to presence of acidic minerals in the soil. Photosynthetic activity of the algae in earthen ponds, decomposition and respiration could also have contributed to acidic condition in the earthen ponds. Decomposition and respiration processes could also have released carbon dioxide to the pond water leading to more acidic condition of pond water. While in the concrete and liner ponds, water is not in direct contact with the soil hence less gases from respiration (some from fish) thus less acidic condition in the liner and concrete ponds water.

Compared to other studies, the mean pH of 8.04 recorded in earthen ponds and 9.47 in concrete ponds in the study area, compares very well but are higher than that of 8.00 in earthen ponds and 9.00 in concrete ponds in Egypt respectively (El –Sherif and El-Feky 2009, Trinity 2011). The results from the study area are higher than those reported by Clemson, (2015) of 9.00 in concrete ponds in Ghana and (Kapinga, 2014) 7.40 in earthen ponds in Mwanza Tanzania.

4.2.3 Dissolved oxygen (mg L^{-1})

The dissolved oxygen in mg l^{-1} during the study period varied (Figure 4.3). The mean dissolved oxygen was 4.15 mg l^{-1} ± 0.143 in earthen ponds, 5.21 mg l^{-1} ± 0.322 in liner ponds and 6.74 mg l^{-1} ± 1.119 in concrete ponds (Table 4.1, Figure 4.3). In concrete ponds, dissolved oxygen readings ranged from 4.22 to 8.00 mg l^{-1}, while the mean dissolved oxygen recorded in earthen ponds ranged from, 3.93 to 4.46 mg l^{-1} and in liner ponds it ranged from 5.17 to 5.25 mg l^{-1} (Figure 4.3). Throughout the study period, dissolved oxygen was consistently high in concrete ponds and lowest in earthen ponds (Figure 4.3, 4.4).

Using one way ANOVA, mean dissolved oxygen values of the three different culture systems investigated were significantly different ($p<0.0001$, df=2). Mean separation using Turkey’s test revealed that dissolved oxygen in concrete culture system was significantly higher than in liner and earthen culture system.

Variation in dissolved oxygen in water is influenced by temperature, transparency, amount of dissolved solids and pond productivity (Kitur *et al.*, 2009). The main source of dissolved oxygen in water is the atmosphere and its concentration varies depending on temperature (Kitur *et al.*, 2009). Water equilibrates toward 100% air saturation, dissolved oxygen levels will also fluctuate with temperature, salinity and pressure changes (Brian, 2014). As such, dissolved oxygen levels in water range from less than 1 mg/L to more than 20 mg/L depending on how these factors interact (Brian, 2014). Dissolved oxygen levels are constantly affected by diffusion and aeration, photosynthesis, respiration and decomposition (Brian, 2014).

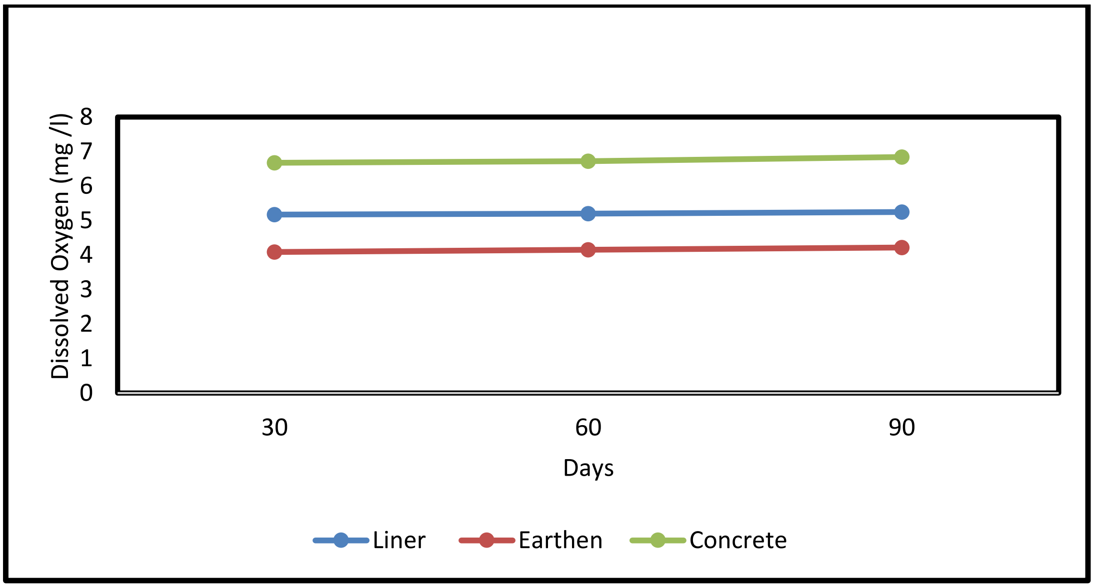


Figure 4.3: Monthly mean dissolved oxygen values recorded in the three culture systems during the study period, August 2015 to November 2015

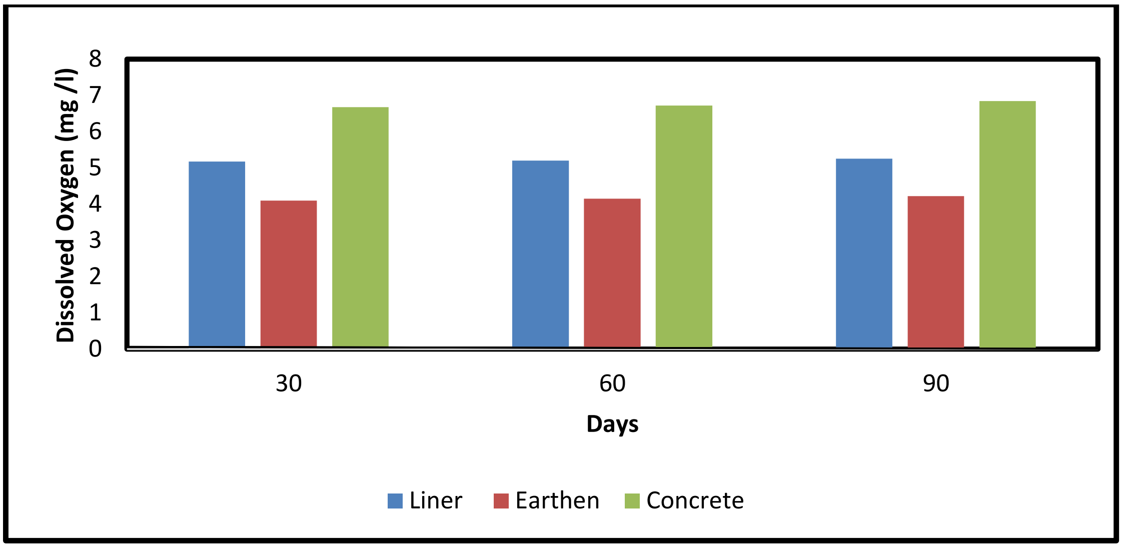


Figure 4.4: Mean dissolved oxygen values recorded in the three culture systems between August 2015 and November 2015

According to Onada *et al.*, (2015) as daylight progressively intensifies, the rate of photosynthesis increases and so does the uptake of CO_2 and release of oxygen but solubility of gases decreases with increase in temperature as heat intensity increases. During the day, removal of CO_2 reduces the concentration of carbonic acid, and pond pH rises including level of oxygen. At night the process reverses and produces carbon dioxide taking up oxygen by the respiration process of the microorganisms (Onada *et al.*, 2015). The more the phytoplanktons in a system, the more the oxygen will be released during the day and vice versa at night.

According to Bryan, (2017), the maximum amount of oxygen that can be dissolved is controlled by the water temperature. Warmer waters hold less dissolved oxygen thancolder waters. If water is too warm, it will not hold enough oxygen for aquatic organisms to survive (Fondriest, 2014) and solubility of oxygen and other gases in water therefore decreases as temperatures increases.

The high dissolved oxygen recorded in the concrete pond could be attributed to the low temperature recorded in the concrete pond as solubility of oxygen in water is dependent on temperature (Figure 4.1). Possibly the materials used for constructing the concrete and liner ponds have more water attracting molecules increasing bound oxygen in the systems hence more dissolved oxygen. The artificial and smooth nature of the concrete and liner pond surfaces could have allowed free and easy water movement increasing aeration and hence dissolved oxygen in the systems as opposed to earthen system where dissolved oxygen was low (Figure 4.3). Also in the earthen system, due to natural processes, oxygen in earthen is used in respiration and decomposition.

The high clearness of water in the liner and concrete systems indicated that water in these systems was possibly free from pollution. Pollution reduces dissolved oxygen in water bodies due to replacement of oxygen molecules by pollutants. The absence of pollution in liner and concrete meant that there were more oxygen molecule spaces and hence more dissolved oxygen in the systems. This possibly led to the high recorded dissolved oxygen values in these systems.

Less turbid water is easily moved by wind compared to turbid water with more suspended particles. The more the less turbid water is moved by wind, the more the aeration increasing dissolved oxygen in water from the atmosphere. The increased aeration of concrete and liner water which were less turbid could have resulted in the higher recorded dissolved oxygen values in the concrete and liner culture systems. Water in the earthen pond was more turbid hence less aeration.

Compared to other studies the mean dissolved oxygen value of 6.74 ± 1.119 recorded in the study in concrete pond is higher than that reported by (Kurt, 2015), 5.74 ± 0.42 in concrete ponds trial of growth performance of *Oreochromis niloticus* in Turkey. The dissolved oxygen in earthen ponds, 4.15 mg l^{-1} is higher than that reported by (Ngugi, 2013) of 2.3 mg l^{-1} in earthen ponds at Sagana National Fish Farm, Kenya. The recorded reading of 4.15 mg l^{-1} in the earthen ponds in the study area is however much lower than (Abdel, 2015 Nobel, 2007) of 6.5 mg l^{-1} in earthen ponds in Pakistan and higher than that of 4.0 mg l^{-1} in Kigoma, Tanzania, (Limbu *et al*., 2016).

4.3 Effects of varied fish pellets on growth performance of *Oreochromis niloticus* in different culture systems

4.3.1 Growth performance of *Oreochromis niloticus* fed on 2 gms fish pellets in the three different culture systems

The growth performance of *Oreochromis niloticus* when fed on 2 gms of fish pellets in three different culture systems showed variations (Figure 4.5). In liner ponds, mean weight gained ranged from 5.33 gms to 6.12 gms, with a mean weight gain of 5.61 gms. In earthen pond weight gained varied from 4.55 to 11.63 gms with a mean weight gain of 9.27±4.085, while in concrete it ranged from 6.84 gms to 6.85 gms with a mean weight gain of 6.85 gms (Table 4.2, Figure 4.5). The overall total weight in grams at the end of the experiment ranged from 36.82 gms in liner to 47.80 gms in earthen ponds (Table 4.2, Figure 4.5). The highest mean weight gain and total weight was recorded in the earthen pond while the lowest mean weight gain and total weight was recorded in the liner ponds (Table 4.2, Figure 4.5). Using one way Anova, there was no significance difference in fish weight gain between the three different culture systems ($F=1.85$, $p=0.237$) (Figure 4.5). Growth performance was rapid for the first 30 days in liner and concrete ponds and then it flattened to the end while in earthen ponds, it grew steadily up to 60 days and then flattened to the end of the experiment.

Differences in fish feed quality, quantity and nutrient composition influence growth performance of organisms differently, (Opiyo *et al.*, 2014, Karim, 2013 Piniji, 2013, Bhujel, 2009). Number of feedings and nutrient composition also influence growth performance. According to Thongrod, (2007), the growth performance of (*Oreochromis niloticus*) fed every day, two times a day with a commercial fish pellet of 26 % crude protein at the recommended feeding rates and frequency, *Oreochromis niloticus* attained 3 – 5 tonnes per hectare in earthen ponds.

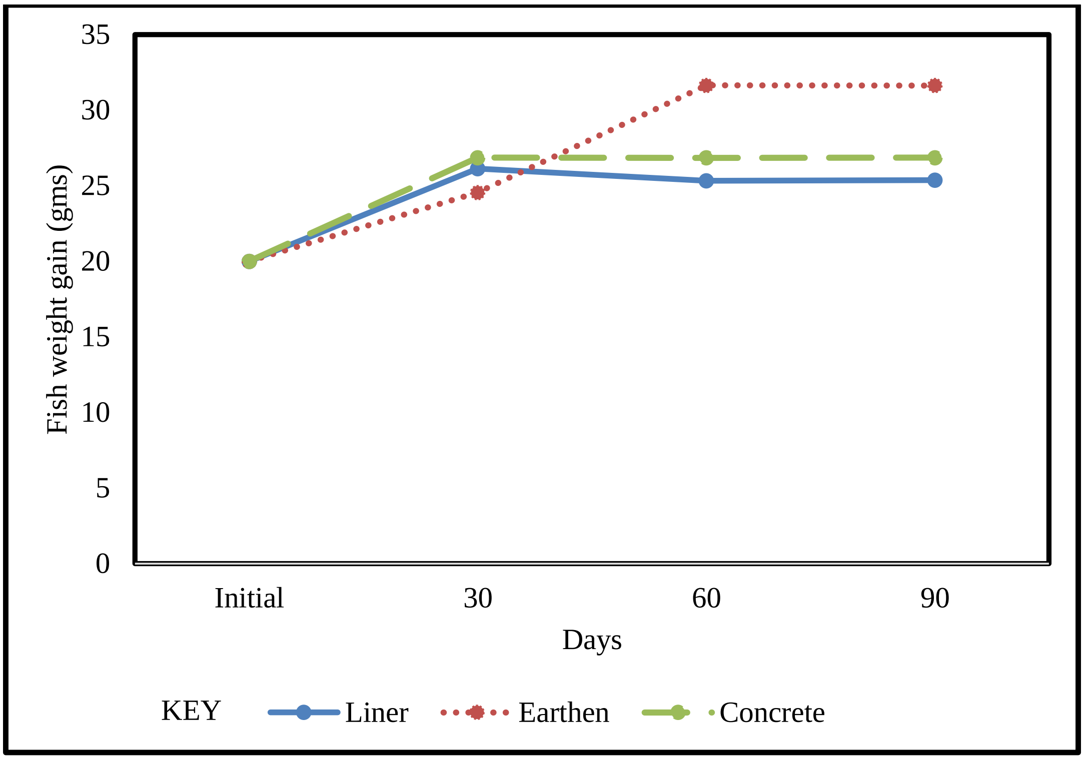


Figure 4.5: Fish mean weight gain in grams when fed on 2 grams fish pellets in three culture systems during the study period (August to November 2015).

This was attributed to the stable natural primary productivity in the earthen ponds and free exchange of nutrients between the pond water and soil in the earthen pond. The structure of the pond and type also influences growth performance of *Oreochromis niloticus* (Akunga *et al.*, 2018). According to Bhujel, (2013) and Ghulam, (2010) fish fed with commercial fish pellets in earthen culture system had a better growth performance than those which were not fed in Thailand.

The steady growth performance of *Oreochromis niloticus* in earthen ponds up to day 60 could be attributed to the addition of food from natural zooplanktons and phytoplankton due to the nature of the bottom of earthen pond which had bottom sediments for growth of micro-organisms. This together with the pellets was responsible for the high weight gain and total weight in the earthen ponds. In the liner and concrete ponds, fish relied only on the artificial source of food and as soon it was depleted, the growth stagnated to the end of the experiment (Figure 4.5).

Table 4.2: Mean weight gain and total weight gain in grams of fish when fed with 2, 4 and 6 grams fish pellets during the study period (August to November 2015).

2 gms fish pellets	**Day**	**Culture systems**			
		Liner	**Earthen**	**Concrete**	
	30	6.12	4.55	6.85	
	60	5.33	11.63	6.84	
	90	5.37	11.62	6.85	
Mean weight gains (gms)		5.61±0.445[a]	9.27±4.085[a]	6.85±0.006[a]	$p = 0.237$
Total weight (gms)		36.82	47.80	40.54	
4 gms fish pellets	30	5.38	5.25	6.59	
	60	9.92	7.80	7.60	
	90	10.00	7.79	6.59	
Mean weight gains (gms)		8.43±2.645[b]	6.95±1.469[b]	6.93±0.583[b]	$p = 0.529$
Total weight (gms)		45.30	40.84	40.78	
6 gms fish pellets	30	7.50	9.13	11.82	
	60	12.23	11.32	11.83	
	90	11.65	11.31	11.82	
Mean weight gains (gms)		10.46±2.580[c]	10.59±1.262[c]	11.82±0.006[c]	$p = 0.569$
Total weight (gms)		51.38	51.76	55.47	
Mean total weight (gms)		44.50	46.80	45.60	
Final total weight (gms)		133.50	140.40	136.79	

Values are expressed as mean ± SE. Values in the same row with different superscript letters are significantly different ($p < 0.05$).

The growth performance in earthen pond to day 60 (Figure 4.5) could also be attributed to the suspended particles in earthen ponds, which consists of periphytons (which are live feeds for fish). The periphytons formed an added source of food for fish in the earthen ponds compared to the other culture systems which had no suspended particles due to the nature of their bottom, one with a liner and the other with concrete.

Table 4.3: Summary of mean weight gain of fish against varied amounts of fish pellets treatments in various days during the study period.

Treatment	Days	Mean weight gain ± SE	*F*-value	*P*-value
2g Fish pellet	30	5.84 ± 0.68		
	60	7.93 ± 1.89		
	90	7.95 ± 1.89	0.579	0.589
4g Fish pellet	30	5.74 ± 0.43		
	60	8.44 ± 0.74		
	90	8.13 ± 0.99	3.781	0.087
6g Fish pellet	30	9.48 ± 1.26		
	60	11.79 ± 0.26		
	90	11.59 ± 0.15	2.930	0.130

Compared to other studies, the recorded production of 47.80 gms in earthen ponds when fish was fed 2 gms of fish pellets, is less than that reported by (Opiyo *et al.*, 2014) of 122.7 gms in earthen ponds in Kenya on feeding the fish with 2 gms of fish pellets. In Pakistan in earthen ponds, fish fed with 2 gms commercial fish pellets recorded a growth performance of 128.32 gms which is higher than 47.80 gms recorded in earthen fish ponds in Meru County, when fish was fed with 2 gms commercial fish pellets (Limbu *et al.*, 2016). The findings of Akunga *et al.*, (2018), Opiyo *et al.*, (2014) and Limbu et al., (2016) are therefore higher than the results of the current study.

4.3.2 Growth performance of (*Oreochromis niloticus)* fed on 4 gms of fish pellets in three different culture systems

The study revealed that growth performance of *Oreochromis niloticus* when fed with 4 gms of fish feed varied during the study period (Table 4.2, Figure 4.6). In liner ponds, mean weight gained ranged from 5.38 gms (30th day) to 10.00 gms (90th day). In earthen ponds mean weight gained varied from 5.25 gms (30th day) to 7.79 gms (90th day).

While in concrete it ranged from 6.59 gms (30th day) to 7.60 gms 60th day, (Figure 4.6). The mean weight gain was 6.93 ± 0.583 gms in concrete ponds, 6.95±1.469 in earthen and 8.43 ± 2.645 gms in liner ponds. Total weight in grams ranged from 40.78 gms in concrete to 45.30 gms in liner ponds (Table 4.2). The highest mean weight gain and total weight was recorded in liner pond (Figure 4.6). The growth performance in the three different culture systems flattened out after day 60 (Figure 4.6).

Using one way Analysis of Variance, there was no significance difference in fish weight gain between the three different culture systems (liner, earthen and concrete ($F = 0.71$, $p = 0.529$) (Table 4.2).

Optimal growth performance of fish is influenced by extraneous factors such as dissolved oxygen, pH and temperature (Ngugi, 2013). According to Chowdhury, (2011) optimal growth performance of fish occurs at an optimal temperature of 25 ^{o}C to 26 ^{o}C, dissolved oxygen of above 5 mg l^{-1} and a pH of 6.8. Different authors have suggested various ambient optimal temperatures for best growth performance of *Oreochromis niloticus.*

According to Frida, (2014), best ambient temperature for tilapia is 21.8 degrees Celsius, (Abdel, 2008) 22 degrees Celsius and (Soltan *et al.*, 2014) 26 degrees Celsius. Mercy,(2018) report that pond liners are good in regulating temperatures between 23 and 28 degrees Celsius and they are good conductors of heat. Liner ponds also keep away small harmful organisms notably harmful weeds which grow at the bottom of ponds reducing productivity of a pond (Mohan, 2019). He also reports that liners improve water quality by keeping pond water clean.

The high growth performance in liner ponds could be attributed to the optimal dissolved oxygen and temperature (Table 4.1, Figure 4.1, and Figure 4.6) which is favourable conditions for the growth of warm water fish. The transparency of water in liner pond could have made it easier for food to be easily visible and hence readily available to the fish for more growth. Since feed was not mixed up with suspended particles, more food was accessible and ready for uptake by the fish hence more growth performance. The liner could have contributed to the high temperature since it is a good absorbent of heat.

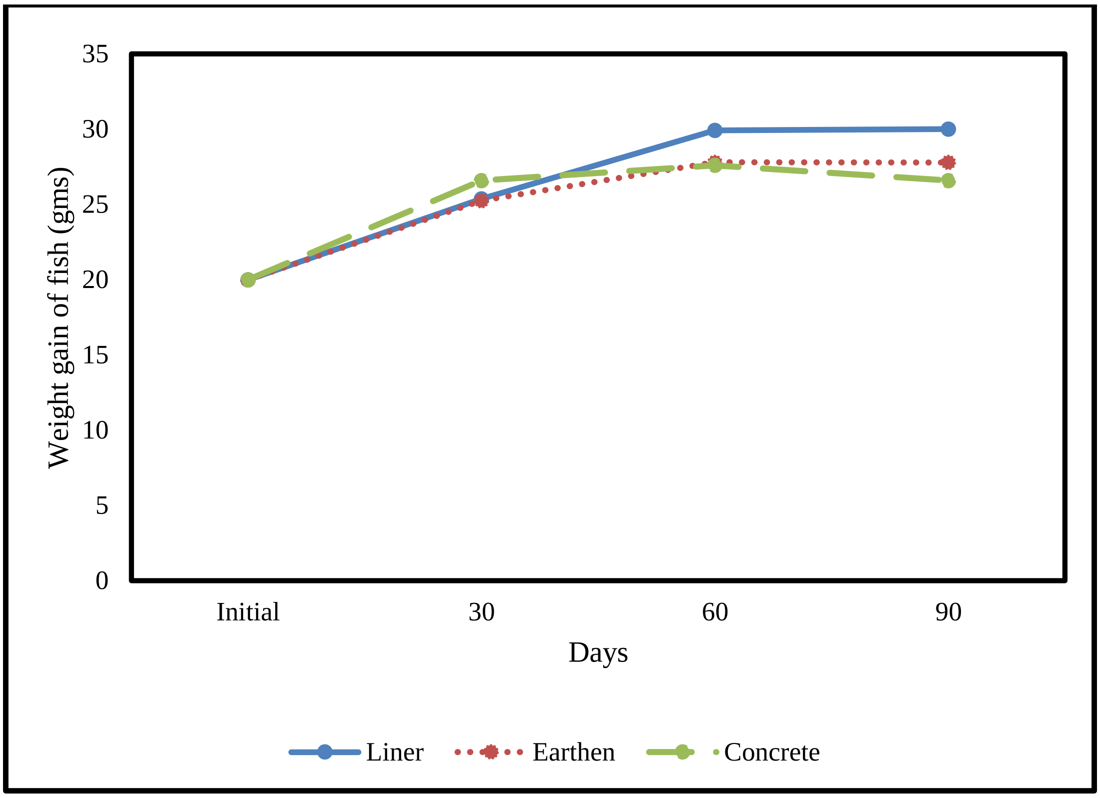


Figure 4.6: Fish mean weight gain in grams when fed on 4 grams fish pellets in three different culture systems during the study period

The poor growth performance in concrete culture system could be attributed to the low temperature recorded in the systems which does not favor the growth of warm water fish (Table 4.1). The high pH (Table 4.1) does not favor the growth of periphytons and hence no additional food from algae, and fish could possibly not locate food easily due to turbidity hence low growth performance (Figure 4.6). In earthen pond, fish growth performance was better than that in concrete due to favourable temperatures 25.11 degrees Celsius (Table 4.1, Figure 4.6) increasing natural productivity hence additional food for the fish. Primary production could also have been higher in earthen culture system due to the fact that the pond water was directly in contact with soil creating natural conditions for primary production. The suspended particles in earthen ponds could also have attracted more periphytons increasing available food for fish. However low pH could have resulted in reduced alkalinity in the earthen pond and this lead to lower growth performance of fish compared to that in liner.

In liner and earthen ponds, leveling out of the weight gain graph occurred after day 60 (Figure 4.6) upto the end of the experiment. While growth performance in concrete declined slightly after day 60. The leveling point (day 60 for all) represents the best time to harvest fish since continued feeding of the fish after leveling out point results in excess use of inputs and hence wastage leading to increase in cost of inputs. The excess food could also lead to pollution of the culture system killing the fish. The leveling out after day 30 in concrete pond could be attributed to declining feeding activity of the fish after getting enough feed.

Compared to other studies, fish mean weight in the current study 40.84 gms in earthen and 40.78 gms in concrete culture systems using 4 gms of fish pellets are much lower than that of 192.20 gms in concrete ponds and 187.79 gms in earthen ponds in Mexico when fish was fed with a similar diet of 4 gms pellets (Gomez-Marquez *et al.*, 2015).

4.3.3 Growth performance of *Oreochromis niloticus* when fed with 6 gms of fish feed in the three different culture systems

Growth performance of *Oreochromis niloticus* fed with 6 gms of fish feed in the three culture systems varied during the study period (Table 4.2). In liner ponds mean weight gained ranged from 7.50 gms to 12.23 gms (Table 4.2) with the highest mean weight gain being recorded on the 60th day of the experiment. In earthen pond mean weight gained varied from 9.13 (30th day) to 11.32 gms (60th day). While in concrete, it ranged from 11.82 gms (30th day) to 11.83 gms (60th day). The average weight gain ranged from 10.46±2.580 gms in liner ponds to 11.82±0.006 gms in concrete ponds.

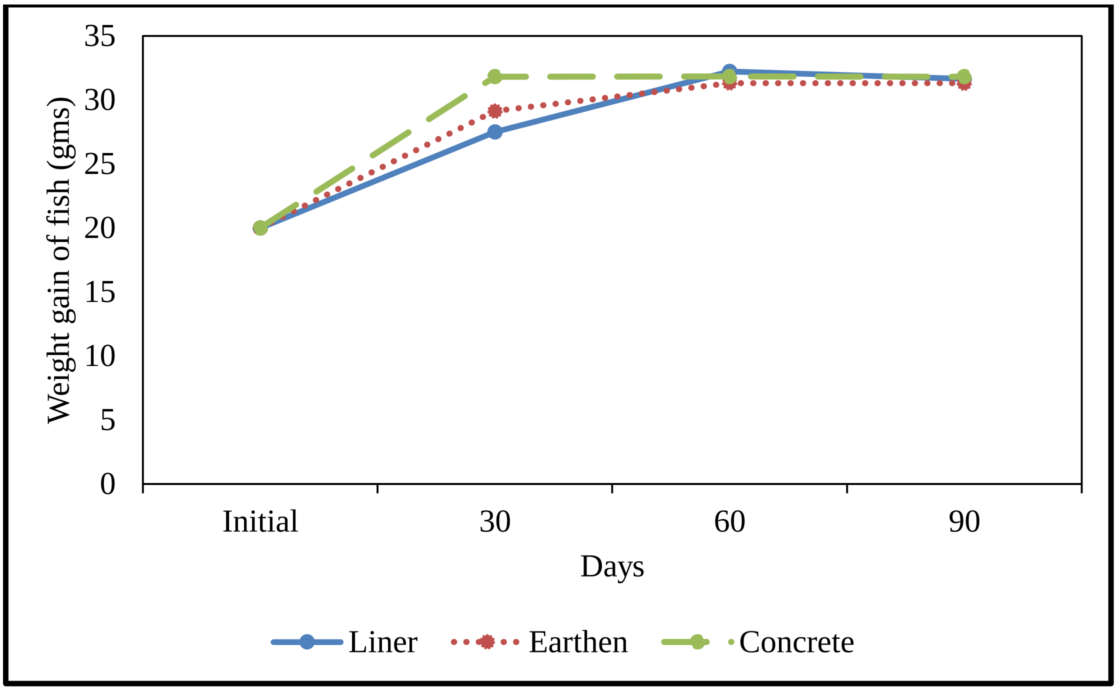


Figure 4.7: Fish mean weight gain in grams when fed on 6 grams fish pellets in three culture systems during the study period (August 2015 to November 2015).

The total weight in grams was 51.38 gms in liner, 51.76 gm in earthen and 55.47 gms in concrete ponds (Table 4.2). The highest mean weight gain and total weight was recorded in concrete pond (Figure 4.7) while the lowest mean weight gain and total Weight was in liner culture system (Figure 4.7). The weight gain graph in all the three culture systems initially increased steadily leveling out after 60 days to the end of the experiment (Figure 4.7). Using Analysis of Variance, the results revealed that the growth performance of *Oreochromis niloticus* was not significantly different between the culture systems (F = 0.62, $p = 0.569$).

There are several factors that affect fish growth performance of *Oreochromis niloticus* (Ngugi, 2013). According to Munguti *et al.*, (2014) nutritional value of fish feed, pH, DO, quantity of feed, temperature, floating properties of fish feed and feeding time influence growth performance of fish. An increase of over 10 times of growth performance (mean weight) of all male *Oreochromis niloticus* fingerlings when they were reared in four outdoor concrete tanks at a stocking density of 4 fish per square metre for 24 weeks in Nigeria was recorded (Okonji *et al.,* 2013). Fingerlings which were fed with a 26 % crude protein diet attained a mean weight of 25.20 gms in a 2m x 1m pond at the end of the 24 weeks while those which were reared only in fertilized pond with algae without feeding with a commercial fish feed attained a mean weight of 2.3 gm (Okonji *et al.,* 2013).

Dhirendra, (2007) reported a growth performance in tilapia of 312±1.8 gm when all male *Oreochromis niloticus* fingerlings were stocked in six 280 square metre earthen ponds at a stocking density of 4 fish per square metres for 90 days and fed with a commercial fish feed of 26 % crude protein. According to Yakubu *et al.,* (2012), fish fed with multi feed at stocking densities of 300 and 450 exhibited the highest feed conversion ratio ($p < 0.05$) compared to the fish fed on local feed (local C.P of 24) in Nigeria for 24 weeks. According to Emmanuel, (2013) a fish growth performance of 201.6 gms was recorded in hapa-in-pond culture system while in cages it was 336 gms in 24 weeks after feeding the fish with commercial fish pellets.

The high growth performance in the concrete culture system could be explained by the fact that, in the 6 gms pellets treatment, feed was not a limiting factor and fish could feed as much as possible to satiation as opposed to the other treatments. The higher pH in concrete ponds and dissolved oxygen (Figure 4.2, 4.3) could have led to increase in alkalinity in the concrete ponds improving conditions for more multiplication of micro-organisms. This might have increased available food for the fish.

Algae multiplication in the pond could also have contributed to the same increasing fish production since fish feed on algae. More live feeds increase food availability in the concrete pond leading to better growth compared to the other culture systems when 6 gms pellets were used, hence the higher recorded weight gain in the concrete culture (Figure 4.7). The absence of suspended particles in the concrete and liner system could have led to better visibility of feed particles making food more available to the fish hence increased feeding, increased growth performance of fish. Stability of the earthen ponds for natural productivity could also have resulted in the steady growth performance of fish in the earthen ponds though lower than in the other culture systems.

The steady increase in weight gain (Figure 4.7) initially followed by leveling out of the graphs could be attributed to the fact that, young fish feed more frequently on small quantities of feed, steadily gaining weight up to an optimal weight gain beyond which any more feeding results in very little weight gain due to satiation hence the flattening or leveling out of the weight gain graph (Figure 4.7). Once satiated, fish feed less frequently and hence the flattening out of the graph in the study after day 60. The leveling out point is a good indicator of feed adjustment point to avoid feed wastage and also to harvest and sell fish. Once an optimal gain in weight is attained, continued feeding of fish is uneconomical. These leveling out points are important since they give an indication of when to harvest fish to avoid excessive costs and wastage of inputs.

According to Attipoe and Mensah, (2013), tilapia fed with 6 gms fish pellets in earthen ponds in Ghana, attained a weight of 150.3 gms in 90 days. Lupatsch and Kissil, (2008) and White, (2007) recorded 180 gms, Noble (2007) 216 gms. Their results are slightly higher, but compare well with the results of the study of 140.40 gms in earthen ponds. Oscar, (2013) reported 175 gms tilapia growth performance in San Francisco which is higher than 140.4 gms in the study using 6 gms fish pellets. Six (6) gms pellets had the highest significant effect on growth performance of fish (Table 4.2, appendix 5b) compared to 2 and 4 gms fish pellets.

4.4 Growth performance of *O.niloticus* on varied quantities of inorganic fertilizer (DAP

4.4.1 Growth performance of fish on fertilizing water with 2 gms DAP

Growth performance of *Oreochromis niloticus* in the three different culture systems when pond water was fertilized with 2 gms DAP showed variations during the study period (Table 4.4). In liner culture system, the mean weight gained varied form 4.84 gms (30^{th} day) to 6.13 gms (90^{th} day). The total weight gain was 19.29 gms while the mean weight gain was 6.43 ± 1.74. In earthen pond weight gain varied from 4.50 gms (30^{th} day) to 7.24 gms (90^{th} day). Total weight gain was 18.99 gms while mean weight gain was 6.33 ± 1.58. In concrete pond, weight gain varied from 7.55 gms (30^{th} day) to 7.75 gms, total weight gain was 22.85 gms and mean weight gain was 7.62 ± 0.12 (Table 4.4, Figure 4.8). Highest total weight gain was 22.85 gms in concrete ponds and the lowest was in earthen culture system 18.99 gms (Figure 4.8).

Using one way Analysis of Variance, the results showed that fish weight gain was not significantly different between the culture systems, (F = 0.83, df = 2, p = 0.479).

Variations in growth performance of fish in fertilized water is brought about by increase in phytoplankton and zooplankton in the culture system, which increases available live feed for fish in the pond leading to more fish production (Dong, 2008, Tacon *et al.,* 2011). Live water organisms comprise of three main categories phytoplankton, nekton and benthic organisms with phytoplankton being the most important to fisheries (Akunga *et al.,* 2018). According to Oscar, (2013) and Sousa, (2012) phytoplankton are very vital in influencing pond productivity in terms of fish yields. It is the lowest trophic level in aquatic food chain in most types of water systems and therefore is utilized as food by aquatic organisms both directly and indirectly (Akunga *et al.,* 2018).

According to Anum *et al.,* (2013) raising the level of fertilization of culture systems increased the growth performance of GIFT (Genetically Improved Farmed Tilapia) by over 10 % and also nutrient composition in the body of the tilapia. Variations in feeding practices and frequency led to increase in fish production in Thailand, (Belton *et al.,* 2009) and (Abdul, 2014).

The high weight gain in concrete culture system could be attributed to good conducive conditions, higher pH, alkalinity and dissolved oxygen in concrete ponds (Figure 4.2. 4.3) with moderate temperature. This could be attributed to the fact that concrete system had no particulate matter and all food was available to the fish. Also this could be due to live feed which grew later as the substrate had to develop before growth of live feed. After food was exhausted, growth performance remained stagnant since there was no further increase in weight of fish due to the feeds having been exhausted. In liner ponds there was steady increase in growth performance upto day 60 after which there was a decline after the pellets got exhausted while in earthen, there was continuous growth performance because of growth of live feeds due to substrate.

However, after day 60, growth performance graph of earthen pond overtook that of liner. This could be attributed to the more stable natural conditions in the earthen ponds and pond fertilization since the water is in contact with soil. In liner system, there was a steady increase of growth performance up to day 60 then a decline. The growth increase in liner could be attributed to higher temperature since the black lining is a good absorber of heat. The higher temperature in liner and fertilization of pond water could have increased primary productivity resulting in more live feeds increasing growth performance of fish. The noted decline in mean fish weight gain after day 60 in liner ponds could be attributed to the fact that, DAP fertilization got depleted leading to limited live food for fish. In the absence of live feeds and pond water fertilization, there was no continuous weight gain. This point is the best for harvesting and selling fish to avoid wastage of inputs or further fish weight loss.

Table 4.4 Fish weight gain in (gms) in different cultured ponds on fertilizing pond water with different amounts of DAP

Treatment (DAP gms)	culture system	30 days	60 days	90 days	Total weight	Mean weight (MW) gain ±SD
2gms	Liner	4.85	8.29	6.15	19.29	6.43 ± 1.74[a]
	Earthen	4.50	7.25	7.24	18.99	6.33 ± 1.58[a]
	Concrete	7.55	7.75	7.55	22.85	7.62 ± 0.12[a]
						p = 0.479
4gms	Liner	1.00	1.75	1.80	4.55	1.52 ± 0.45[a]
	Earthen	6.58	8.17	8.16	22.91	7.64 ± 0.92[b]
	Concrete	11.67	18.70	11.67	42.04	14.01± 4.06[c]
						p = 0.002
6gms	Liner	7.10	13.40	13.33	33.83	11.28± 3.61[c]
	Earthen	7.83	9.67	9.66	27.16	9.05 ± 1.06[c]
	Concrete	12.00	12.03	12.00	36.03	12.01± 0.02[c]
						p = 0.296 n = 3

Values are expressed as mean ± SE. Values in the same column having different super-script letters are significantly different ($p < 0.05$). Wtg = Weight gain, Tw = Total weight gain and Mw = Mean weight gain ±SD.

Compared to other studies, mean weight of 217 grams in earthen ponds in Egypt (Saad *et al.,* 2014) is higher than that recorded in earthen ponds of 18.99 gms in the study area when *Oreochromis niloticus* was fed with 2 gms pellets and ponds fertilized with 2 grams DAP. Also 134.80 g recorded in concrete ponds in Kenya (Waidbacher *et al.,* 2007) is higher than that recorded in concrete ponds of 22.85 g in the study area due to alkaline conditions of the concrete ponds improving water quality and disinfecting the ponds.

Table 4.5: Summary of fish weight gain in (gms) in different cultured ponds on fertilizing pond water with different amounts of DAP

Treatment (DAP gms)	Culture system	Mean weight (MW) gain ± SD	F-value	*P*-value
2gms	Liner	6.43 ± 1.74^{a}		
	Earthen	6.33 ± 1.58^{a}		
	Concrete	$7 .62 \pm 0.12^{a}$		
	F- value	0.832		
	p - value	0.479	2.904	0.131
4gms	Liner	1.52 ± 0.45^{a}		
	Earthen	7.64 ± 0.92^{b}		
	Concrete	14.01 ± 4.06^{c}		
	F-value	20.068		
	p-value	0.002*	0.187	0.002
6gms	Liner	11.28 ± 3.61^{c}		
	Earthen	9.05 ± 1.06^{c}		
	Concrete	12.01 ± 0.02^{c}		
	F-value	1.502		
	p - value	0.296	1.568	0.283
				n = 3

Mean values in the same column having different superscript letters are significantly different ($P \leq 0.05$). Wg = Weight gain, Mw = Mean weight gain ±SD. Mean separated using LSD

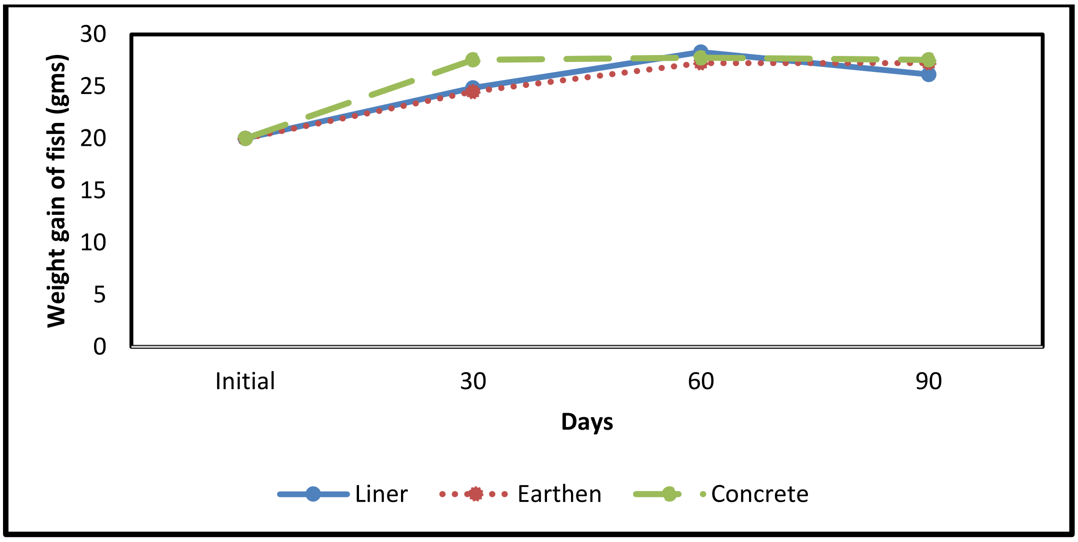


Figure 4.8: Fish mean weight gain in grams when pond water was fertilized with 2 gms DAP in the three culture systems during the study period (August 2015 to November 2015).

4.4.2 Performance of fish on fertilizing pond water with 4 gms DAP

The study showed that on fertilizing pond water with 4 gms DAP, growth performance of fish in the different ponds varied. In liner culture system weight gain varied from 1.00 gms (30th day) to 1.80 gms (90th day). Total weight gain was 4.55 gms while the mean weight gain was 1.52 ± 0.45 gms (Table 4.4, Figure 4.9). In earthen pond weight gain varied from 6.58 gms (30th day) to 8.16 gms (90th day). Total weight gain was 22.91 gms while mean weight gain was 7.64 ± 0.92. In concrete pond, weight gain varied from 11.67 gms (30th day) to 18.70 gms, total weight gain was 42.04 gms and mean weight gain was 14.01 ± 4.06 (Table 4.4). Highest weight gain 14.01 ± 4.06 g was in concrete ponds and the lowest weight gain 1.52 ± 0.45 g was in liner culture system (Figure 4.9).

According to Jack and Patricia, (2014), fertilizing a pond with inorganic fertilizers or manure stimulates and expands the plankton and phytoplankton population thereby increasing productivity of a pond per unit area. According to Waidbacher *et al*., (2007), San, (2008) and Atufa *et al.*, (2015), growth performance of fish is influenced by fertilization of pond and amount of feed. Claude, (2018) reports that, pond fertilization increases concentrations of nitrogen, phosphorus and other plant nutrients stimulating phytoplankton photosynthesis that is the base of the food web culminating in increased fish production.

Fertilizing a fish pond stimulates the growth of microscopic plants called algae (Banrie, 2013). These algae are eaten by zooplanktons and insects which serve as food for water organisms increasing production including that of fish. He also noted that, the algae makes the pond water turn green which helps to shade the pond bottom, preventing growth of troublesome rooted weeds and increasing pond productivity. Pond fertilization can increase fish yields three to four times (Banrie, 2013).

Growth performance of fish in concrete ponds increased steadily to day 65 after which, there was a sharp decline. In earthen ponds there was steady increase in growth performance of fish upto day 30 then gradual increase to the end of the experiment. In liner ponds, there was a low gradual growth performance of fish upto the end of the experiment (Figure 4.9). Using Analysis of Variance, the results revealed that there was significant difference in the growth performance between the culture systems (F = 20.07, df = 2, p = 0.002) (Table 4.4, 4.5). Turkey's test revealed that fish growth performance in concrete culture system was significantly higher than in earthen and liner culture systems.

The high weight gain in concrete culture system as compared to the other systems could be attributed to the fact that, since there were no suspended particles in the concret ponds and the slightly higher alkaline conditions compared to the other systems coupled with addition of phosphorous and nitrates, possibly improved mineral content of pond water and this led to growth and multiplication of micro-organisms producing additional food for the fish hence increase in weight compared to the other culture systems. However after day 65, growth performance of fish in concrete pond started declining and this could be possibly due to the fact that, live feed and fish feeds had gotten finished resulting in limited food after fertilization was depleted hence dismal growth performance of fish (Figure 4.9, appendix 8). The best time to carry out fish harvesting is day 65 when mean fish weight gain is highest.

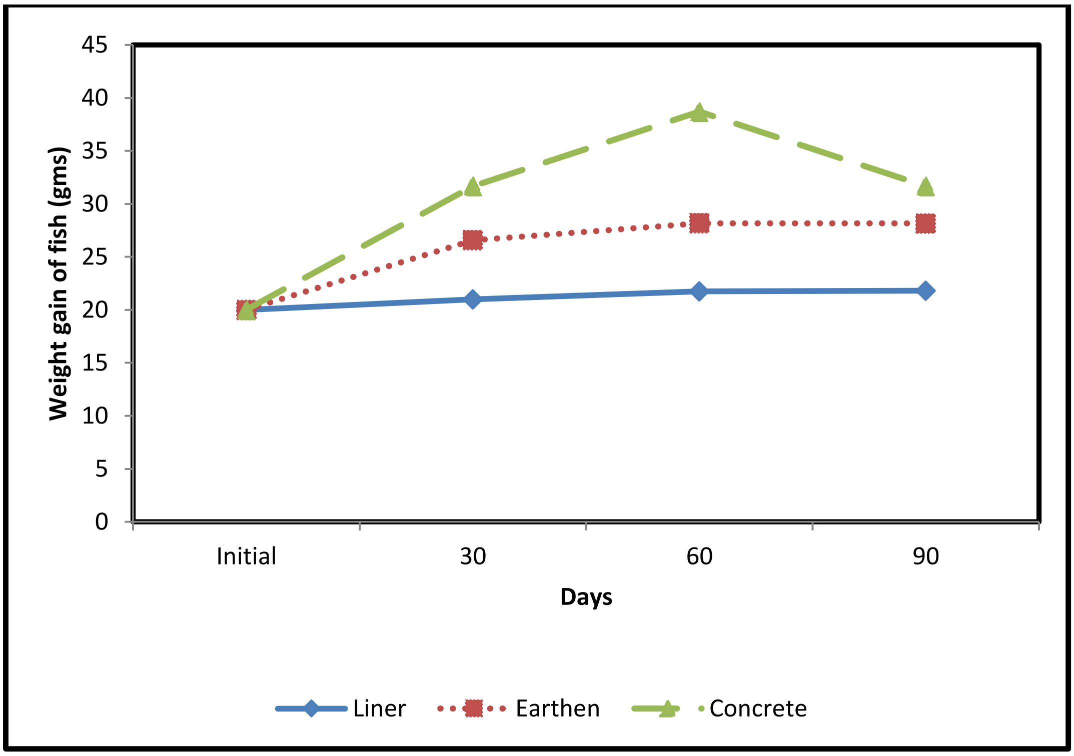


Figure 4.9: Fish mean weight gain in grams when pond water was fertilized with 4 gms DAP in the three culture systems during the study period (August 2015 to November 2015).

Growth performance of fish in the earthen system increased moderately though less than in the concrete culture system to day 30, 60 and 90 after which the growth performance flattened out (Figure 4.9). Earthen system is moderately stable compared to the other systems and that is why probably there were no drastic changes in the system. The low dissolved oxygen in earthen pond could have slowed feeding behavior of fish. Water in earthen pond is in direct contact with the soil, decomposition and respiration processes could have released carbon dioxide which is very vital for photosynthetic primary productivity process. Hence the slight rise in the graph of growth performance of fish in earthen pond after day 30. The leveling out points represent the best time to harvest the fish to avoid wastage of inputs.

Excessively high temperatures in liner ponds could have inhibited microbial activity and fish feeding behavior causing the constantly low growth performance of fish in the system. Probably decomposition and respiration depleted dissolved oxygen in liner ponds decreasing feeding behavior of fish in the system leading to slow growth performance of fish upto the end of the experiment. At day 90, there is low growth performance of fish and therefore further additional of fertilizers will lead to wastage.

Comparing growth performance of fish at 2 gms and 4 gms DAP, earthen and concrete culture systems performed better at 4 gms DAP ($p = 0.002$) than at 2 gms DAP. This could be attributed to the fact that, with application of more DAP, there were more nutrients (phosphates and nitrates) for increased natural productivity. Availability of more phosphates after addition of DAP possibly removes the limiting factor of fish growth by increasing multiplication of micro-organisms in water.

According to Sorphea *et al.*, (2010) a growth performance of 24.93 g was recorded in fertilized earthen ponds in Colombia with 4 g DAP. The results compare well but are slightly higher than those of the current study of 22.91 in earthen ponds with 4 g fertilization rate. Sen, (2010), in concrete ponds of same size in Pakistan, a growth performance of 96.03 g was recorded when the ponds were fertilized with 4 g DAP and fish fed on a commercial diet. His findings are higher than the production of 42.04 gms in the current study. Most farmers have not been using concrete pond which exhibits a higher growth performance of fish compared to the other culture systems.

4.4.3 Weight of fish on fertilizing water with 6 g DAP

The growth performance of *Oreochromis niloticus* when pond water was fertilized with 6 g DAP in three different culture systems showed variations (Figure 4.10). In liner culture system, the mean weight gained varied form 7.10 gms (30^{th} day) to 13.33 gms (90^{th} day). The total weight obtained was 33.83 gms while the mean weight gain was 11.28 ± 3.61 gms (Table 4.4, Figure 4.10). In earthen pond, weight gain varied from 7.83 gms (30^{th} day) to 9.66 gms (90^{th} day). Total weight was 27.16 gms while mean weight gain was 9.05 ± 1.06 gms (Table 4.4). In concrete pond, weight gain varied from 12.00 gms (30^{th} day) to 12.03 gms with total weight of 36.03 gms while the mean weight gain was 12.01 ± 0.02 gms (Table 4.4). Highest weight gain of 12.01 ± 0.02 gms was in concrete ponds and the lowest (9.05 ± 1.06) was in earthen culture system (Figure 4.10, Table 4.4). In concrete and earthen ponds, growth performance of fish increased slowly upto day 30 then flattened out. Increase in growth performance in liner ponds grew steadily from start and after day 60, the growth performance in liner was not affected, it overtook that in other culture systems. Using one way Analysis of Variance, the results showed that fish weight gain were not significantly different between the ponds, (F = 1.50, df = 2, p = 0.300) when pond water was treated with 6 gms DAP.

The use of inorganic and organic fertilizers in extensive, semi-intensive and intensive production systems greatly influences growth performance of aquatic organisms especially fish, but considerable differences exist in the type of fertilizers used, their availability, cost, and application rates (Tacon *et al.,* 2011). According to El-Sayed, (2007) tilapia farmers in Egypt generally use a single application of sometimes DAP and urea at rates of 35 and 25 kg/ha, respectively) mostly in earthen ponds before fish stocking. In addition, many farmers start feeding their fish about one month after stocking.

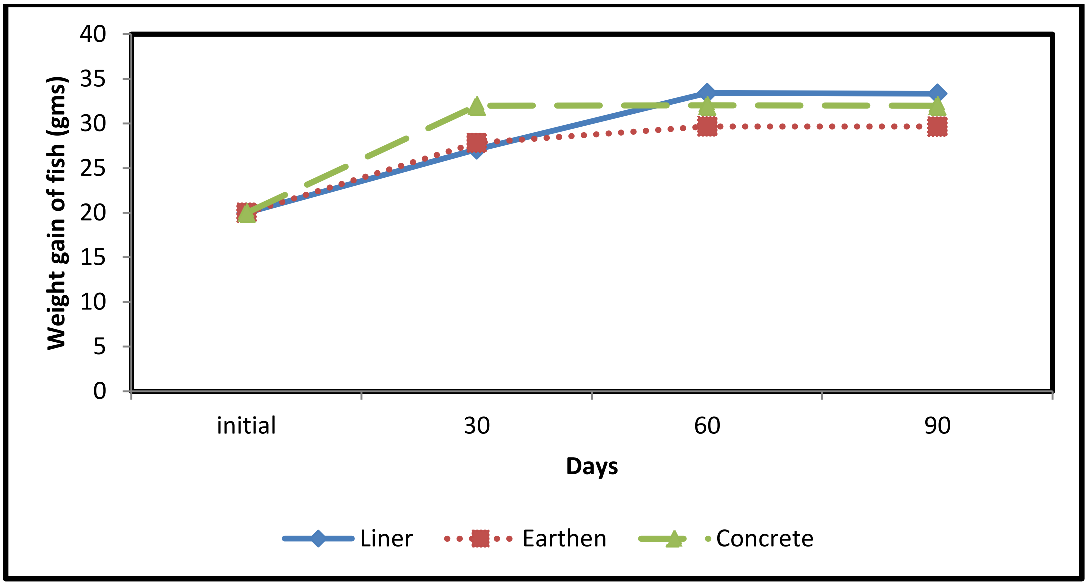


Figure 4.10: Fish mean weight gain in grams when pond water was fertilized with 6 gms DAP in the three culture systems during the study period (August 2015 to November 2015)**.**

According to Claude, (2018) pond fertilization increases concentrations of nitrogen, phosphorus and other plant nutrients, stimulate phytoplankton photosynthesis that is the base of the food web culminating in increased fish production. Fertilization results in two to fivefold increase in aquaculture production of all species of fish. This is due to, high phytoplankton abundance and zooplankton diversity which is achieved with fertilization (Sebastian, 2016). According to Mwangi, (2017) fertilized earthen ponds in Kirinyaga Kenya had a higher growth performance of fish than ponds which had not been fertilized. In Ghana, liner and concrete ponds which had been fertilized recorded higher weight gain of *Oreochromis niloticus* than those which had not been fertilized (Duodu, 2015). Pond fertilization can increase growth performance of fish by stimulating the growth of algae which are eaten by zooplankton and insects which serve as food for fish

(Banrie, 2013). Algae also make the water turn green, which helps to shade the pond bottom, preventing growth of troublesome rooted weeds and filamentous algae (moss or pond weeds) especially in earthen ponds (Banrie, 2013).

The high weight gain in concrete culture system could be attributed to more productivity due to favourable alkaline conditions. The walls and bottom of the concrete pond are made of limestone which increase hardness of water leading to good water quality by eliminating any acidic conditions which lower water quality. Growth performance in the concrete pond increase upto day 30 after which it stayed high to the end of the experiment. The increase in nitrogen and phosphorus in the pond coupled with good water quality might have increased algae in the pond raising aquatic biomass productivity of the pond due to increased nutrient content of the system. The clearness of water in concrete ponds could also have contributed to more light penetration enhancing primary productivity process in the concrete ponds. Fish growth performance in the liner pond was steady upto day 60 then flattened out. Possibly substrate growth towards the end of the experiment due to warm conditions in liner might have increased live feeds available to the fish increasing weight of fish (Table 4.1). Presence of more nitrates, phosphorous and favourable alkalinity could have contributed to additional food for the fish hence good growth performance of fish. Absence of suspended particles in liner pond could have made food more visible and available to the fish hence increased growth performance in the liner though not the best.

The low production in earthen ponds could be attributed to the low pH in the earthen ponds leading to less micro-organic activity hence limited food for the fish leading to low productivity in the earthen culture system. Low dissolved oxygen also might have led to less feeding activity of the fish. A lot of DAP, algae decomposition could also have led to low dissolved oxygen for fish growth. All the growth performance graphs in the three culture systems levelled out after day 60 possibly due to the declining effect of fertilization and limited feed for fish which got exhausted.

The final mean weight of 24.82 g in earthen ponds in Kenya when fed commercial fish pellets of 26 % crude protein and pond fertilized with 6 g DAP (Opiyo *et al.,* 2014) is slightly lower than the final weight (27.16 g) in the study when treated similarly. Other studies done in concrete ponds fertilized with 6 g DAP in Malawi (Kassim *et al.,* 2015) and fish fed with 26 % commercial feed, the final mean weight of 28.10 g was lower than the 36.03 g found in concrete ponds in the study when the ponds were fertilized with 6 g DAP and fish fed with similar diet. However, if DAP is applied in excess, it can lead to deterioration of water quality, negatively affecting growth performance of fish.

4.5 Varying amounts of lime

4.5.1 Weight of fish on liming the pond with 2 gms lime

The study revealed that growth performance of *Oreochromis niloticus* varied when the amount of lime in the treatment was varied (Table 4.6, Figure 4.11).When the treatment was 2 grams lime, mean weight gain in liner pond ranged from 5.50 gms to 10.60 gms and total weight was 26.60 gms with mean weight gain of 8.87 ± 2.92. In earthen pond weight gain varied from 5.13 gms (30th day) to 5.61 gms (90th day). Total weight was 16.36 gms while mean weight gain was 5.45± 0.28. In concrete pond, weight gain varied from 6.10 gms to 6.11 gms, total weight was 18.32 gms and mean weight gain was 6.11 ± 0.01 (Table 4.6). Highest weight gain was in liner ponds and the lowest was in earthen culture system (Figure 4.11).

In all the three culture systems (liner, earthen and concrete), growth performance of *Oreochromis niloticus* increased steadily to day 30 after which growth performance in liner overtook that in earthen and concrete and continued to increase steadily upto day 60 then flattened out to the end of the experiment. In concrete, flattening out of growth performance occurred after day 30 while in earthen culture system, flattening out occurred at day 60. Using one way Analysis of Variance, the results showed that fish weight gains were not significantly different in the ponds, (F = 3.44, df = 2, $p = 0.101$) when pond water was limed with 2 gms lime, $p \geq 0.05$.

According to Siddik, (2007) liming of the ponds serves to disinfect the culture systems, corrects water qualities conditions by raising pH to optimal levels increasing production of micro-organisms in the ponds and hence natural food. Liming application improves phosphorus availability in ponds. However, he points out that, not all ponds require lime application and that lime requirement can be determined by analysis of pond soil or pond water hardness (Gary, 2015). According to Sultana *et al.*, (2013) and Karim, (2013), growth performance of fish is influenced by liming, fertilization of pond water and amount of fish feed given to fish.

According to Queiroz *et al.*, (2015) agricultural lime reacts quickly to increase total alkalinity hence pH of pond water to acceptable concentrations within 2 weeks of application. He further observed that, effectiveness of lime application did not differ among treatments methods, direct application over the pond water surface or spreading uniformly over the bottom of the empty pond then filling the pond with water for stocking.

Liner pond had less suspended particles, hence a lot of food was visible and available to the fish, increased feeding leading to higher fish production. The slightly high temperatures (Table 4.1), in the liner ponds could also have led to increase in multiplication of microorganisms and photosynthetic process leading to increase in algae and aquatic biomass productivity, hence the high recorded growth performance of fish in the liner ponds. The higher temperatures in the liner ponds are due to release of more heat which was trapped by the black bottom polythene material used to line the pond. Addition of lime in the liner system leads to improvement in mineral nutrient (calcium) which was from the lime. Solubility of minerals is better at optimal temperatures (24.90 degrees Celsius) according to (Maina *et al.,* 2013). Improvement in mineral nutrient improves productivity of the liner system leading to better growth performance of fish. After day 30 growth performance in liner culture system overtook that in other ponds possibly due to better feeding of fish and more nutrients hence higher growth performance of fish.

According to Claude, (2016), ammonium containing fertilizers like DAP are acid forming because of oxidation of ammonium to nitrate causing alkalinity to decline. Frequent liming of pond water therefore increases alkalinity for increased natural productivity. Liming therefore improves effectiveness of fertilization in pond water hence increased fish production (Claude, 2016).

Liming sterilizes and disinfects the liner pond increasing alkalinity which is good for primary productivity and growth of microscopic organisms (food for the fish). Food for fish in liner ponds is no longer limited increasing growth performance of fish in the ponds. At the high temperature (25.72±0.297 degrees Celsius Table 4.1), solubility of calcium, magnesium and phosphorus possibly increases in the liner pond water increasing mineral content of the water. According to Maina *et al.,* (2013) solubility of minerals increases at about 24.90 degrees Celsius.

Table 4.6: Weight gain values of fish in gms recorded on treating pond water with varying amounts of lime between August 2015 to November 2015

Treatment	Culture system	30 days	60	90	Total weight	Mean wt. gain ±SD
2 gms	Liner	5.50	10.50	10.60	26.60	8.87± 2.92[a]
Treatment	Earthen	5.13	5.62	5.61	16.36	5.45± 0.28[a]
with lime	Con-crete	6.11	6.10	6.11	18.32	6.11 ± 0.01[a]
						p = 0.101
4 gms	Liner	6.50	4.50	4.45	15.45	5.15 ±1.17[a]
Treatment	Earthen	5.62	7.25	7.24	20.11	6.70± 0.94[b]
with lime	Con-crete	7.36	7.38	7.36	22.10	7.37± 0.01[c]
						p = 0.049
6 gms	Liner	1.80	10.58	10.40	22.78	7.59± 5.02[a]
Treatment	Earthen	9.15	9.25	9.24	27.64	9.21± 0.06[a]
with lime	Con-crete	13.14	13.15	13.14	39.43	13.14 ±0.01[a]
						p = 0.130
						n = 3

Values are expressed as mean ± SE. Values in the same column having different superscript letters are significantly different (P < 0.05).

Addition of lime to the earthen ponds could have led to release of phosphorus and nitrogen into the soil leading to slightly less alkaline conditions (pH 7.94 Appendix 2) in earthen ponds which might not have favoured growth of live microscopic organisms as food for the fish leading to low growth performance of fish. Ngugi, (2013) recommends a pH of up to 9 for good growth of *Oreochromis* niloticus in Kenya. The low temperature (24.71 degrees Celsius Appendix 2) could have slowed process of primary production resulting in limited food in earthen ponds due also to low algae growth.

Table 4.7: Summary of fish weight gain in (gms) on treating pond water with varying amounts of lime between August 2015 to November 2015

Treatment	Culture system	Mean wt. gain ± SD
2 gms Treatment with lime	Liner	8.87± 2.92[a]
	Earthen	5.45 ± 0.28[a]
	Concrete	6.11 ± 0.01[a]
	F – value	3.443
	p-value	0.101
4 gms Treatment with lime	Liner	5.15 ±1.17[a]
	Earthen	6.70± 0.94[b]
	Concrete	7.37± 0.01[c]
	F-value	5.183
	p-value	0.049*
6 gms Treatment with lime	Liner	7.59± 5.02[a]
	Earthen	9.21± 0.06[a]
	Concrete	13.14 ±0.01[a]
	F-value	2.911
	p-value	0.131
		n = 3

Values are expressed as mean ± SD. Values in the same column having different superscript letters are significantly different ($P \leq 0.05$). Mean separated using LSD

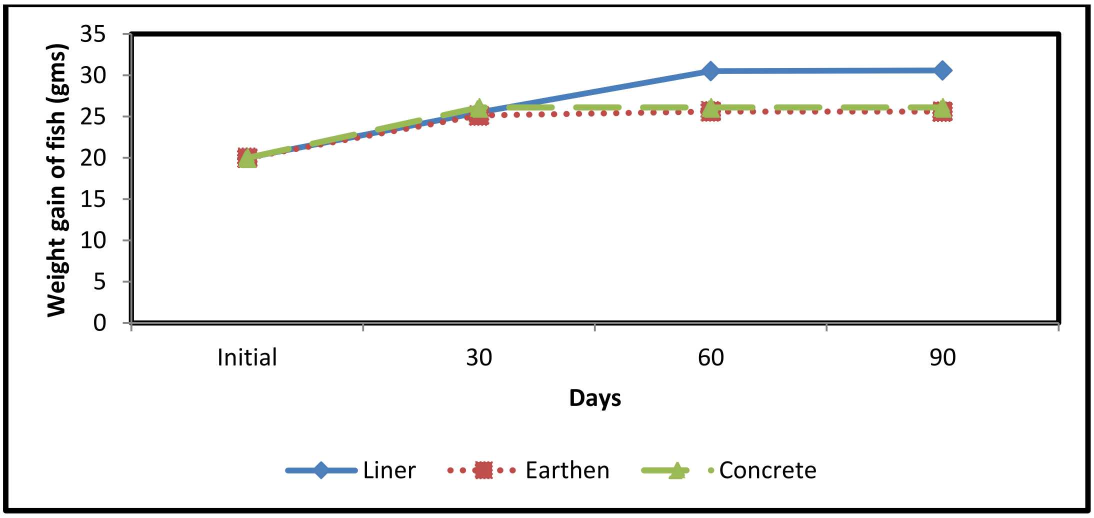


Figure 4.11: Fish mean weight gain in grams when pond water was limed with 2 gms lime in the three culture systems during the study period (August 2015 to November 2015).

According to Veeramani and Santhanam, (2015) growth performance of tilapia is best at 28 degrees Celsius in India. Concrete is a poor conductor of heat hence low energy release in the concrete culture system. The low temperature of 21.87 degrees Celsius (Appendix 2) in concrete pond could have contributed to the low growth performance of fish due to limited food in the system. Low temperatures slows multiplication of algae, micro-organisms leading to slow growth performance of fish.

After 30 days, graph of weight gain in earthen and concrete culture systems started leveling out while in liner culture system, the weight gain graph increased steadily up to day 60 when it also started leveling out (Figure 4.11). There was marked variation in fish growth performance graph between the liner culture system, earthen and concrete systems after day 60. Weight gain in earthen and concrete were lower than in liner. This could be attributed to the fact that, food was not a limiting factor in liner culture system at this point. Possibly this could be due to the fact that low temperature which could have been the limiting factor was not present in liner ponds (25.72±0.297 Table 4.1). Solubility of minerals could have been high in liner due to the warmer conditions in liner improving water quality and conditions for more live food availability. In concrete it was 21.85±0.300 degrees Celsius (Table 4.1). The high temperature in liner possibly is responsible for high primary productivity hence higher growth performance of fish in the liner culture system. The flattening out points represent the optimal harvest points of fish to avoid wastage of inputs (Figure 4.11), since there is no more gain in weight at these points and weight of fish is not increasing.

Compared to other studies, Gomez-Marquez *et al*., (2015), reported that, all male *Oreochromis niloticus* tilapia fingerlings raised in limed concrete ponds with 2 g lime and fed with a commercial fish feed, attained a weight of 32.03 gms in 90 days in Mexico in concrete ponds. Which is higher than 18.32 gms in concrete culture system with 2 g lime in the study.

4.5.2 Weight of fish on liming the pond with 4 gm lime

The growth performance of *Oreochromis niloticus* in the three different culture systems when pond water was treated with 4 g lime showed marked variations over the study period. In liner culture system, the mean weight gained when pond was limed with 4 gms lime varied from 6.50 gms to 4.45 gms (Table 4.6, Figure 4.12). The total weight gain was 15.45 gms while the mean weight gain was 5.15 ± 1.17. In earthen pond, weight gain varied from 5.62 gms (30^{th} day) to 7.24 gms (90^{th} day) and total weight gain was 20.11 gms while mean weight gain was 6.70 ± 0.94. In concrete pond, weight gain varied from 7.36 gms to 7.38 gms, total weight gain was 22.10 gms and mean weight gain was 7.37 ± 0.01 (Table 4.6, Figure 4.12). Highest weight gain was thus in concrete ponds and the lowest was in liner culture system (Figure 4.12).

Initially growth performance of fish in the three culture systems increased steadily, with fish growth in concrete leading upto day 30 after which the growth performance in concrete flattened out. In earthen, fish growth performance continued increasing slightly to day 60 then flattened out. In liner ponds, growth performance of fish decreased slightly to day 60 then flattened out. Using Analysis of Variance, the results revealed that the effect of 4 gms level of pond liming had a significant effect on the growth performance of *Oreochromis niloticus* between the culture systems ($F = 5.18$, $df = 2$, $p = 0.049$). Comparison of means using Turkey's test revealed that growth performance of fish was highest in the concrete culture pond and lowest in liner pond. The best time to harvest fish in the concrete system was day 30 ($F = 633541.167$, $p = 0.0001$, appendix 11). In earthen ponds, best time to harvest was also on day 60 ($F = 34.315$, $p = 0.001$, appendix 11).

According to Dong, (2008), supplemental feeding and liming of culture system influences productivity per unit area of aquatic organisms. In Egypt, an increase in growth performance, yield and net returns of *Oreochromis niloticus* was recorded when reared in limed earthen ponds (Saad *et al.*, 2014). They found that, fish in limed ponds produced higher economic returns.

Production within the entire food chain (plankton-insects-fish) is stimulated by liming and the increased abundance of natural food items support fish growth performance (Louis *et al.,* 2009). He further states that, liming can enhance growth of rooted aquatic plants that serve as nursery areas for young fish. According to Louis *et al.,* (2009) liming improves water quality, fish health, sterilizes pond water and increases mineral content of water by addition of calcite (calcium and magnesium). He adds that liming aids in release of phosphorus from pond water improving fertility of water in pond water. Liming also neutralizes any acidic condition in the pond increasing alkalinity.

According to Flamm *et al.,* (2016), draining and liming of fish ponds disinfects and removes pathogens from the pond water, improving the health of fish. In Glessen German, fish ponds which were drained and limed, tested negative for cyprinid herpes virus 3 (cyHv – 3) in fish as opposed to fish ponds which were not treated with lime which tested positive for *Cyprinid herpes virus* 3. Diseases and pathogens affect fish growth performance lowering fish yields in fish farms (Ngugi, 2013).

Initially growth performance of tilapia increased steadily upto day 30 in all the three culture systems possibly due to the liming effect which sterilizes and disinfects pond water improving quality of water and mineral content of water by addition of calcium, magnesium and phosphorus. Liming also increases alkalinity by continuing to neutralize any acidic conditions improving growth performance of fish. The high

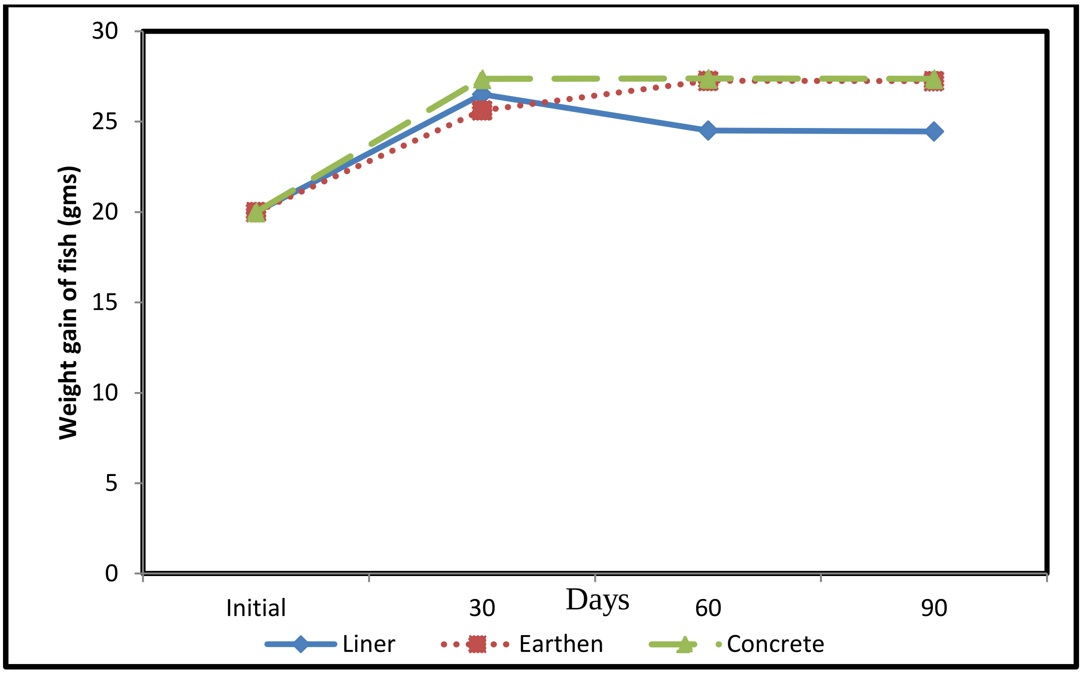


Figure 4.12: **Fish mean weight gain in grams when pond water was limed with 4 gms lime in the three culture systems during the study period (August 2015 to November 2015)**.

growth performance of fish in concrete culture system as compared to the other systems could be attributed to additional alkalinity (pH 9.47±0.170 Table 4.1) associated with added lime and calcium/magnesium from the pond construction materials (walls and bottom of pond). This might have led to higher primary productivity as a result of increased multiplication of micro-organisms producing more food for the fish.

The added lime could have improved nutrient capacity (calcium, magnesium and phosphorus) of the water in concrete pond making more food available hence increased growth performance of fish. Due to good transparency in concrete pond water, feeding of fish was not inhibited since food particles were easily visible to the fish improving feeding. Good light penetration could have aided increased aquatic multiplication of micro-organisms and algae leading to high growth performance of fish since food was not a limiting factor in the system. Growth performance was at its peak on day 90, best time to harvest fish to maximize on profit. Further feeding of fish would lead to loss of income since there is no more addition of fish weight beyond this point.

In the three culture systems growth performance was steady upto day 30 after which growth performance in liner ponds started declining. Addition of lime in the system disinfects and improves water quality by reducing hydrogen ions in the system responsible for acidic condition. The low production in liner ponds after day 30 could be attributed to less feeding activity of fish in liner ponds and limited food as a result of limited live feeds. The decline in mean weight gain of fish in liner ponds could be attributed to the fact that food for the fish got depleted faster and decomposition and respiration processes could have depleted available oxygen for growth leading to limited food.

Natural productivity in earthen ponds was more stable due to the natural nature in earthen ponds and that is why there was no decline in them. Water in earthen ponds is in direct contact with the soil and the liming process could have increased release of phosphorus from the soil increasing mineral nutrient of the water hence natural primary productivity was maintained at a moderate level. Four (4) grams level of liming produced the most significant growth performance of fish possibly due to the fact that, optimal alkalinity was achieved at this level of liming. Liming could have contributed to more mineral nutrient by addition of calcium and magnesium to pond water. Best time to harvest fish from the earthen ponds was on day 90 after which the growth performance of fish leveled out. Further feeding of fish after day 90 would be uneconomical leading to loss of income.

After day 60 there was further decline in growth performance of fish in liner ponds while in the other culture systems there was flattening out of the recorded growth performance (Figure 4.12) representing the best time to harvest fish. The decline in growth performance in the culture ponds could be attributed to lime being depleted hence low alkalinity and low natural productivity. The low alkalinity could also have led to low water quality affecting movement and feeding behavior of fish.

According to Sahoa *et al.,* (2013) growth performance of *Oreochromis niloticus* of 33.50 gms was recorded in limed concrete ponds with 4 g lime in New Papua Guinea and fish fed with 4 gms commercial fish feed which is higher than that of 22.10 gms in the current study.

4.5.3 Weight of fish on liming the pond with 6 gms lime

Growth performance of *Oreochromis niloticus* varied when the three different culture systems were treated with 6 g lime. In liner pond fish weight gain ranged from 1.80 gms to 10.40 gms and total weight gain was 22.78 gms with mean weight gain of 7.59 ± 5.02 (Table 4.6, Figure 4.13). In earthen pond weight gain varied from 9.15 gms (30^{th} day) to 9.24 gms (90^{th} day). Total weight gain was 27.64 gms while mean weight gain was 9.21 ± 0.06. In concrete pond, weight gain varied from 13.14 gms to 13.15 gms, total weight gain was 39.43 gms and mean weight gain was 13.14 ± 0.01 (Table 4.6, Figure 4.13). Highest weight gain was thus in concrete ponds and the lowest was in liner culture system (Figure 4.13).

Growth performance of fish rose sharply in concrete and earthen ponds upto day 30 then flattened out. Rise of growth performance was higher in concrete than in earthen ponds. In liner ponds there was a slow increase of fish growth performance upto day 30 after which the performance increased steadily to overtaking that in earthen at day 60 then flattened out after day 60. Using one way Analysis of Variance, the results showed that growth performance of fish was not significantly different between culture systems. (F = 2.91, df = 2, *p* = 0.130) when ponds were limed with 6 gms lime.

Liming reduces hydrogen ions and/or aluminum in acidic pond waters neutralizing acidity and improving productivity (Wurts, 2013). He further states that, liming enhances the effect of fertilization, prevents wide swings in pH and adds calcium and magnesium in pond water improving alkalinity.

According to Louis *et al*., (2009) liming influences pond productivity by buffering ponds from rapid fluctuations in pH, supply calcium, decrease water acidity enhancing abundance and diversity of aquatic life. According to Sauoo, (2012) liming increases total alkalinity or hardness of pond water, mineral content of water, sterilization, precipitation of excess organic matter decreasing demand for dissolved oxygen and maintains optimal carbon dioxide supply for optimal plant photosynthesis. Adam

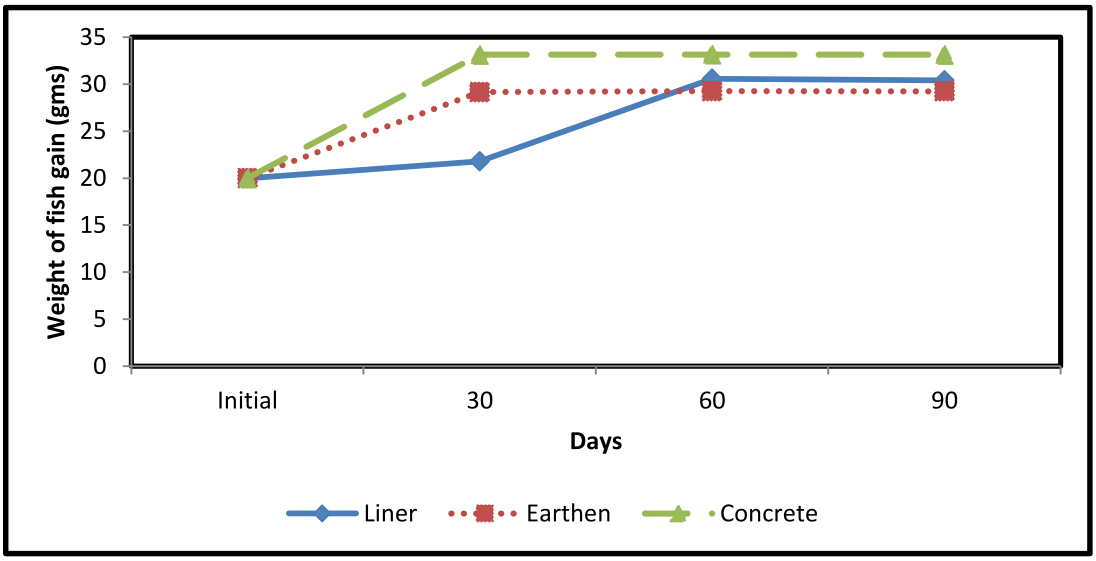


Figure 4.13: Fish mean weight gain in grams when pond water was limed with 6 gms lime in the three culture systems during the study period (August 2015 to November 2015).

, (2012) and Mischke, (2012) reported increased production of 15,000 tons/ha per year of *Oreochromis niloticus* in concrete ponds which had been limed compared to 6,500 tons/ha per year in ponds which were not limed in Thailand.

The higher production recorded in the concrete ponds could be attributed to addition of more lime (four (4) grams producing the most significance growth performance) which possibly reduced hydrogen ions and / or aluminum in the concrete pond water leading to higher pH (Table 4.1) hence high alkalinity increasing primary productivity in the concrete ponds. Addition of lime could have increased mineral content (calcium and magnesium) of water improving conditions that enhanced the process of photosynthesis increasing productivity of the concrete culture system resulting in more live feeds for the fish hence higher growth performance of fish in the concrete ponds. Possibly due to less suspended particles in concrete pond water, there was penetration of more sunlight which is very vital for primary productivity and algae growth, hence increased phytoplankton activity increasing fish growth performance.

Liming the pond possibly buffers pH, increases fertility and disinfects water improving quality of water more in the concrete ponds than in liner and earthen. Walls and bottom of concrete ponds was made of limestone materials and this increased alkalinity. Coupled with the fact that food particles are more visible in concrete due to less suspended particles, feeding of fish consequently improved, increasing fish growth performance in the concrete more than in the other culture production systems. Liming also possibly maintains carbon dioxide (very crucial for photosynthetic process) at optimal levels in concrete ponds than in the other ponds for optimal photosynthetic activity. Additionally, liming stabilizes the pH and increases calcium necessary for natural productivity of the ponds at optimal pH better in concrete culture system than in the other systems. Liming could also have increased precipitation of excess organic matter from the concrete pond water compared to the other ponds decreasing demand for dissolved oxygen, hence more oxygen dissolved oxygen in the concrete ponds , 6.74 mg l^{-1} ± 1.119 (Table 4.1).

In liner growth of substrate might have delayed leading to the initial low growth performance in liner culture system due to limited live feeds. Growth of substrates possibly picks after day 30 causing the steady growth due to more live feeds in the system to the end of the experiment but with concrete being higher. In earthen there was growth upto the end of the experiment due to favourable natural conditions producing live feeds for steady growth of fish hence the steady increase in growth performance of fish though lower than in concrete.

After 30 days, fish growth performance in earthen and concrete ponds started flattening out possibly due to the fact that, the feeds and lime had gotten finished. Decomposition process could also have come to an end limiting the amount of carbon dioxide in the system available for any primary production. Due to diminishing food for the fish, growth performance of fish slowed and hence the flattening out of the fish growth performance in earthen and concrete culture systems. In liner ponds, due to the high temperatures (25.72±0.297 degrees Celsius, Table 4.1), high solubility of the minerals increasing mineral content of water, and good light penetration as a result of less suspended particles, there was possibly moderate primary production of food for the fish, hence food was no longer a limiting factor after day 30 and fish growth performance continued increasing steadily upto day 60 when the food and lime got exhausted in the liner ponds causing the flattening out of fish growth performance after day 60. Throughout the experiment, the concrete fish growth performance was constantly higher than that of liner and earthen (Figure 4.13). After day 60, fish weight gain in liner culture system overtook weight gain in earthen ponds after which it leveled out. Initially fish weight gain in liner ponds was lower than in concrete and earthen. The leveling out points indicate optimal weight gain in fish and the best time to harvest or crop fish since there is no weight gain or loss at these points. The leveling out points represent optimal levels of feeding beyond which any further feeding, fish will not continue ingesting feed and the excess feeds in the pond could lower water quality leading to fish mortality. If pollution of the water continues, mass deaths of fish will take place in the ponds.

Compared to other studies, the total fish weight of 39.43 gms in the concrete ponds in the current study is much lower than that of (Dagne, 2013), 108.20 gms and (Sultana *et al.*, 2013), 111.82 gms in limed concrete ponds in Pakistan with 6 g. According to Siddik, (2007) *Oreochromis niloticus* recorded a growth performance of 23.95 gms in concrete limed ponds with 6 g lime compared to a mean weight gain of 16.98 gms in concrete ponds which had not been limed. His findings are slightly lower than the recorded growth performance of 39.43 g in the concrete ponds in the present study.

4.6 Combination of fish pellets, fertilizer and lime

4.6.1 Weight of fish fed on 2 gms of fish feed and pond water treated with 2 grams lime and 2 grams DAP in the different culture systems

The study revealed that growth performance of *Oreochromis niloticus* in the three different culture systems when fed on a combination of different amount of feed and pond water treated with different (DAP and lime amounts), showed variations (Table 4.8, Figure 4.14). In liner culture system, the mean weight gained when fish was fed 2 gms pellets and pond water treated with 2 gms DAP and lime varied from 4.23 gms

(30th day) to 7.50 gms (90th day). The total weight was 19.39 gms while the mean weight gain was 6.46 ± 1.93. In earthen pond weight gain varied from 4.50 gms (30th day) to 8.68 gms (90th day). Total weight was 25.35 gms while mean weight gain was 8.45 ± 3.84. In concrete pond, weight gain varied from 7.93 gms to 8.13 gms, total weight was 23.99 gms and mean weight gain was 8.00 ± 0.12 (Table 4.8). The highest mean weight gain was in earthen ponds and the lowest was in liner culture system (Figure 4.14). Using one way Analysis of Variance, the results showed that fish weight gain was not significantly different among the three types of ponds, (F = 0.09, df = 2, p = 0.911).

According to Mbugua, (2007), different pond inputs, their quality and quantity affect growth of fish in different ways. Growth performance of fish is influenced by quality and quantity of feeds among other factors including nature and frequency of feeding schedules (Munguti *et al.,* 2014). According to Safina *et al.,* (2012) and Suresh *et al.,* (2013), it is very important to use inputs, such as agricultural lime and DAP to treat pond water as it increases its fertility. Bassey and Ajah, (2010) reported a growth performance of *Oreochromis niloticus* of 420 gms (market size) in Calabar Nigeria in a concrete culture system where the fish was fed with a compounded commercial fish feed in limed and fertilized artificial lentic ponds. The higher production in the earthen culture system could be attributed to good natural prevailing conditions (pH of 8.04±0.091), optimal temperature, 25.11±0. 1 degrees Celsius (Table 4.1), increasing algae, zooplanktons and phytoplanktons activity hence enhanced fish growth performance due to increased live feeds in the water as it increases its fertility. Bassey and Ajah, (2010) reported a growth performance of *Oreochromis niloticus* of 420 gms (market size) in Calabar Nigeria in a concrete culture system where the fish was fed with a compounded commercial fish feed in limed and fertilized artificial lentic ponds.

The available food for the fish in the earthen pond could have therefore increased adding to the inorganic feeds which were already being given to the fish. The low natural conditions (dissolved oxygen of 5.21±0.322 mg l^{-1}) possibly due to warmer temperatures in the liner ponds could have contributed to less feeding behavior of fish leading to low productivity hence the low recorded production in the liner culture system.

The decline in fish growth performance in earthen culture system after day 60 could be due to the fact that food for the fish got finished as a result of diminishing of inputs in the earthen ponds. Respiration and decomposition process could have exhausted available oxygen for the fish reducing feeding behavior of fish. The flattening out in concrete and liner ponds after day 30 and 60 respectively could be due to limited oxygen and food for the fish after attaining optimal weight gain since the systems were no longer productive due to diminishing fertility and water quality. The flattening out points represent the best time to harvest fish to avoid further wastage of inputs.

According to Mahfuzul, (2013) tilapia fingerlings reared in limed and fertilized ponds with DAP and fish fed on commercial fish pellets (2 g of each), two times a day, the fish attained a growth performance of 244.72 gms in earthen ponds in three months in Bangladesh. His findings are higher than the results of the study of 25.35 gms in earthen culture system. The fish total weight of 23.99 gms in concrete ponds in the current studyis much lower than that of (Asase, 2013), 169.15 gms in concrete ponds in Ghana with 2 g of inputs.

4.6.2 Weight of fish fed on 4 gms of fish feed and pond water treated with 4 grams lime and 4 grams DAP in the different culture systems

Table 4.8: Weight gain values in (gms) when fish was fed with a combination of Pellets, DAP and Lime between August 2015 and November 2015

Treatment	**Culture system**	**30 days**	**60**	**90**	**Total weight(gms)**	**Mean weight gain ± SD**
2 gms lime, 2 gms DAP	Liner	4.23	7.65	7.50	19.39	6.46 ±1.93[a]
and 2gms pellets	Earthen	4.50	12.17	8.68	25.35	8.45± 3.84[a]
	Concrete	7.93	8.13	7.93	23.99	8.00 ± 0.12[a]
						p = 0.614
4 gms lime, 4 gms	Liner	1.37	6.38	6.23	13.98	4.66 ±2.85[b]
DAP and 4g pellets	Earthen	5.88	9.19	9.18	24.25	8.08 ± 1.91[b]
	Concrete	7.90	8.00	7.90	23.80	7.93 ± 0.06[b]
						p = 0.134
6gms lime, 6 gms	Liner	11.51	11.50	11.51	34.52	11.51±0.01[c]
DAP and 6 gms	Earthen	10.25	11.25	11.24	32.74	10.91±0.57[c]
pellets	Concrete	6.85	14.81	13.69	35.35	11.78±4.31[c]
						p = 0.911
						n = 3

Values are expressed as mean ± SE. Values in the same column having different superscript letters are significantly different ($P < 0.05$).

Growth performance of fish in the three culture systems showed variations when the pond water was treated with 4 g lime, 4 g DAP and fish fed with 4 g commercial fish pellets (Figure 4.15). The mean weight of fish gained in liner culture system varied from 1.37 gms (30^{th} day) to 6.23 gms (90^{th} day). Total weight gain was 13.98 gms while the mean weight gain was 4.66 ± 2.85 gms (Table 4.8, Figure 4.15). In earthen pond weight gain varied from 5.88 gms (30^{th} day) to 9.18 gms (90^{th} day). Total weight gain was 24.25 gms while mean weight gain was 8.08 ± 1.91. In concrete pond, weight gain

Table 4.9: Summary of fish weight gain values in (gms) when fish was fed with a combination of Pellets, DAP and Lime between August 2015 and November 2015

Treatment	Culture system	Mean weight gain ± SD
2 gms lime, 2 gms DAP and 2gms pellets	Liner	6.46 ± 1.93^{a}
	Earthen	8.45 ± 3.84^{a}
	Concrete	8.00 ± 0.12^{a}
	F-value	0.529
	p-value	0.614
4 gms lime, 4 gms DAP and 4g pellets	Liner	4.66 ± 2.85^{b}
	Earthen	8.08 ± 1.91^{b}
	Concrete	7.93 ± 0.06^{b}
	F-value	2.862
	p-value	0.134
6gms lime, 6 gms DAP and 6 gms pellets	Liner	11.51 ± 0.01^{c}
	Earthen	10.91 ± 0.57^{c}
	Concrete	11.78 ± 4.31^{c}
	F-value	0.094
	p-value	0.911
		n = 3

Mean values in the same column having different superscript letters are significantly different ($P \leq 0.05$). Mean separated using LSD

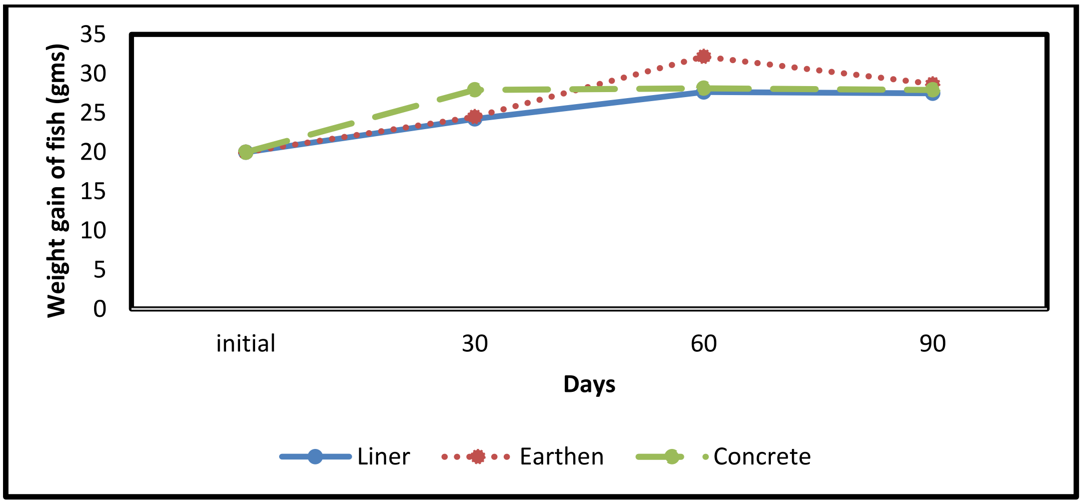


Figure 4.14: Fish mean weight gain in grams when pond water was treated with a combination of 2 gms pellets, 2 gms DAP and 2 gms lime in the three culture systems during the study period (August 2015 to November 2015).

varied from 7.90 gms to 8.00 gms, total weight gain was 23.80 gms and mean weight gain was 7.93 ± 0.06 (Table 4.8, Figure 4.15). Highest weight gain and total weight was in earthen while the lowest weight gain and total weight was in liner culture system.

In concrete and earthen culture systems, there was steady increase in fish growth performance upto day 30 flattening out in concrete while in earthen growth performance of fish continued increasing overtaking that in concrete pond just before day 60 and then flattened out at day 60. In liner ponds growth performance of fish slightly increased to day 30 after which there was a steady increase upto day 60 then flattened out (Figure 4.15). Using one way Analysis of Variance, the results showed that fish weight gain were not significantly different in the three culture systems, (F = 2.86, df = 2, p = 0.134).

Growth performance of various species of fish is affected by the type of feed and level of crude protein in fish diet (Ngugi, 2013). Good growth in tilapia species occurs from fish diets with over 25 % crude protein while in other species of fish like trout, good growth takes place from a proteinous fish diet containing 40 % crude protein and above (Munguti *et al*., 2014). According to Yakubu *et al.,* (2012) growth performance of fish is influenced by quality of fish feed, amount of feed and stocking density of fish in fish ponds.

According to Mwangi, (2017) growth performance of African catfish increases with increasing dietary protein levels upto 35 % crude protein and is better in fertilized ponds compared to unfertilized ponds. He further states that, fish farmers should follow efficient feeding and fish pond fertilization strategies with inclusion of rice milling byproducts in fish diets to reduce feed costs inorder to improve productivity in aquaculture. In tilapia culture, greater controls over water quality and fish nutrition

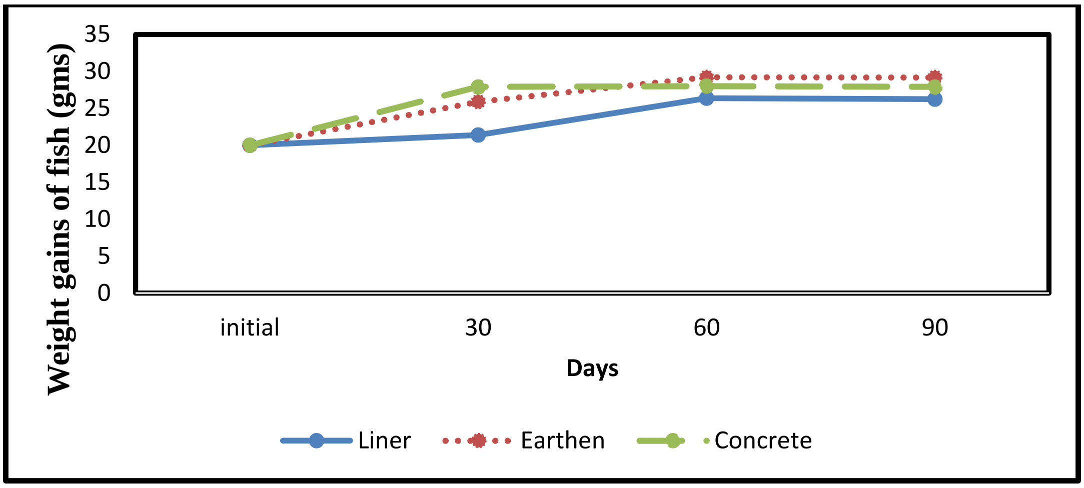


Figure 4.15: Fish mean weight gain in grams when pond water was treated with a combination of 4 gms pellets, 4 gms DAP and 4 gms lime in the three culture systems during the study period (August 2015 to November 2015).

increases production costs and fish yields per unit area (Tick, 2012) and (Kochva, 2009). According to Tick, (2012) and Dang, (2011) growth performance of *Oreochromis niloticus* was 22 % higher in fertilized ponds with biodigester effluent compared with those which were not fertilized.

The high production recorded in the earthen and concrete culture systems respectively could be due to enhanced effect of the interaction effect of the different added nutrients combining to create quality food chain and quality primary production increasing growth performance of fish. The available higher live feed amounts for the fish in the earthen and concrete pond could have therefore increased, hence the higher production figures recorded in the two systems.

The acidic condition in the liner ponds (Table 4.1) could have contributed to low productivity leading to the low recorded production in the liner pond system. The acidic conditions in the liner ponds probably could have interfered with feeding of fish, leading to less production of algae and other micro-organisms which is food for the fish. The leveling out of the mean weight graphs could be attributed to diminishing input amounts in the culture systems leading to reduced microbial activity, less live feeds in the culture systems hence reduced fish production. These points represent the best time to harvest fish to avoid excess use of inputs since the fish is not gaining any more weight.

Leveling out of growth performance of fish started on day 30 in concrete ponds while in liner and earthen ponds, growth performance increased steadily up to day 60 when flattening out occurred in earthen and liner culture systems (Figure 4.15). Initially, the weight gain graph in earthen pond was lower than in concrete pond. After day 60, the weight gain graph in earthen culture system overtook that of concrete culture system. This could be attributed to the steady increase in available food for the fish in the earthen pond possibly due to more algae growth and high photosynthetic process compared to concrete. In earthen ponds, water is in contact with soil thus presence of natural conditions for natural primary productivity. Growth performance of fish in liner ponds with 4 gms of inputs was slightly lower than with 2 gms of input while there was no big change in growth performance of fish in earthen and concrete at both levels of input (2 and 4 gms).

According to Waidbacher *et al.,* (2007), a growth performance of tilapia of 134.8 g was recorded in concrete ponds in Nairobi with usage of 4 g of DAP, 4 g lime and 4 g commercial fish pellets. Their findings are higher than the recorded growth performance of 23.80 g in the study. In Thailand in earthen ponds, a growth performance of 60.00 g was recorded on treating the pond water with 4 g DAP, 4 g lime and fish fed on 4 g fish pellets of 30 % crude protein (Belton *et al.,* 2009; Rahman,

2012) . Their results are higher than the recorded 24.25 g growth performance in earthen ponds in the current study.

4.6.3 Weight of fish fed on 6 gms of fish feed and pond water treated with 6 grams lime and 6 grams DAP in the different culture systems

The study revealed that, growth performance of *Oreochromis* niloticus showed variations when fish in the three culture systems were fed with a combination of different amounts of fish pellets and pond water treated with varying amounts of lime and DAP. In liner pond, weight gain varied from 11.50 gms to 11.51 gms, total weight was 34.52 gms and mean weight gain was 11.51 ± 0.01 (Table 4.8, Figure 4.16). In earthen pond weight gain varied from 10.25 gms (30th day) to 11.24 gms (90th day). Total weight was 32.74 gms while mean weight gain was 10.91 ± 0.57. In concrete culture system, the mean weight gained varied form 6.85 gms (30th day) to 13.69 gms (90th day). The total weight was 35.35 gms while the mean weight gain was 11.78 ± 4.31 (Table 4.8, Figure 4.16). Highest fish growth performance was in concrete culture system and the lowest was in earthen culture system.

There was steady increase in growth performance in all the three culture systems initially with that in concrete being less than the others, there was flattening out of the growth performance on day 30 in liner and earthen culture systems while in concrete culture system, growth performance of fish continued increasing steadily overtaking that of liner and earthen performance up to day 60 then declined slightly (Figure 4.16). After day 60, there was a big variation in the growth performance of fish in concrete ponds, which was higher than that of liner and earthen systems.

Using ANOVA, the results showed that mean growth performance of fish was not significantly different in the three culture systems (F = 0.09, p = 0.911).

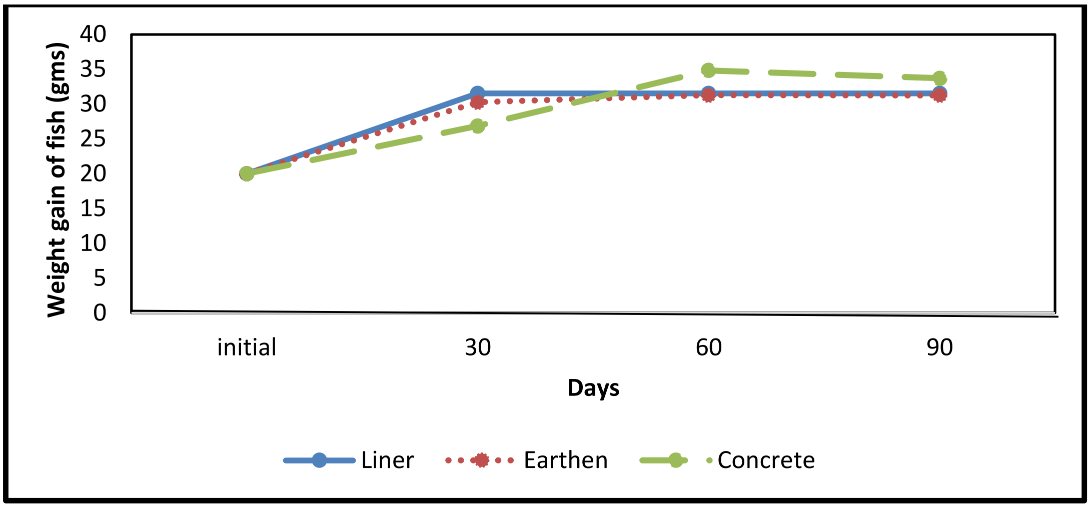


Figure 4.16: Fish mean weight gain in grams when pond water was treated with a combination of 6 gms pellets, 6 gms DAP and 6 gms lime in the three culture systems during the study period (August 2015 to November 2015).

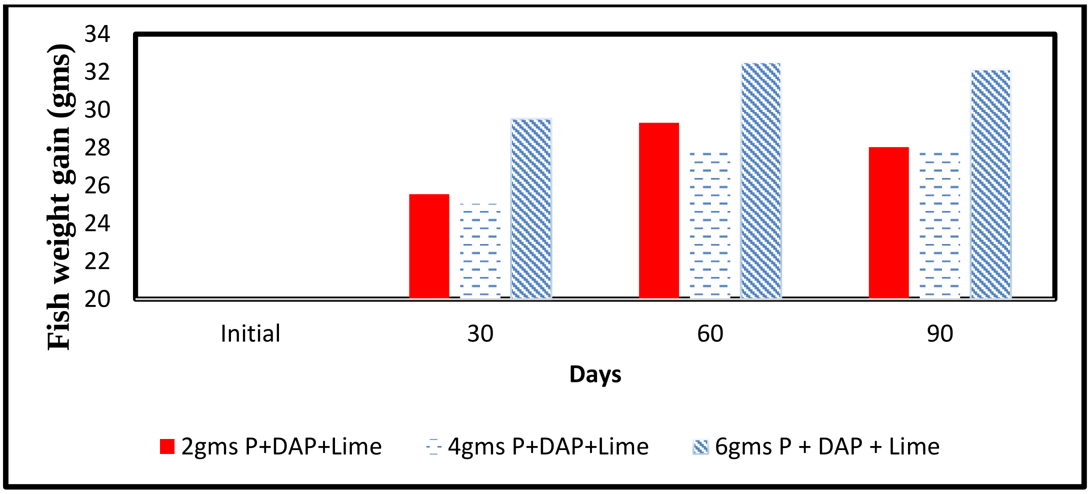


Figure 4.17: Fish weight gains when fed on a combination of (Pellet, DAP and Lime) after 30 days, 60 and 90 days

Besides extraneous conditions, quality of feed, fertilizer and lime affect the productivity of an intensive culture system for rearing fish (Bassey and Ajah, 2010). They reported a weight gain of 420 gms of tilapia fish when tilapia fingerlings were reared for six months in limed concrete ponds and fish fed with a commercial fish feed of 36 % crude protein in fertilized earthen ponds in Turkey compared to a weight gain of only 109 gms in culture systems where fish were reared in ponds with only liming treatment.

According to Opiyo *et al*., (2014), *Oreochromis niloticus* grew to a mean weight of 122.47 gms when the fish was reared in fertilized, limed earthen ponds and fed with a commercial fish feed of 32.7 % crude protein for six months in Kenya, compared to fish which was fed with a local fish feed of only 16.0 % crude protein where fish attained only 91.5 gms, ($P<0.05$).

Domesticated *Oreochromis niloticus* fed a 40 % crude protein commercial fish pellets displayed a significant ($p < 0.05$) superior growth performance over *Oreochromis andersonii* in terms of weight gain (Wegener, 2016). According to Chandra *et al.,* (2013) and Islam, (2014) *Oreochromis niloticus* reared in limed, fertilized and fish pellets enhanced with a promoter in Bangladesh, fish showed significant ($p < 0.05$) growth performance of 4650 kg/acre compared to a growth performance of 3666 kg/acre of fish fed with feeds which had not been treated. Individual growth performance of fish of 0.32 g was recorded with a stocking density of 2000 fish/hapa in Bangladesh in limed, fertilized earthen ponds and fish fed on 35 % crude protein fish pellets for 28 days (Masum, 2011). According to Masum, (2011), an individual growth performance of 0.17 g was recorded with a stocking density of 6000 fish same period.

The high fish growth performance in concrete culture system as compared to the other systems could be attributed to more calcium from addition of lime improving nutrients of pond water resulting in improved water quality. Calcium ions are vital for cell formation and multiplication increasing primary productivity of the concrete pond water. Lime addition could have increased alkaline conditions therefore higher pH in concrete ponds leading to more multiplication of micro-organisms producing more live feeds, algae for the fish, more growth performance of fish. The low production in earthen ponds could be attributed to the low microbial activity due to acidic condition leading to low production. The high production at this level of 18 gms in the culture systems compared to the other levels could be attributed to more input effects due to the higher amounts of the inputs at this level compared to the other level of inputs.

The flattening out of the fish growth performance (Figure 4.16) and the decline ingrowth performance of fish in concrete ponds could be attributed to reduced photosynthesis and respiration leading to less live feeds and hence less fish production. These leveling out points are the best points to harvest fish to maximize on inputs usage since further feeding of fish will not result in any weight gain of fish after attaining optimal weight.

Final mean fish weights recorded in the control ponds in all the culture systems were relatively lower than in those treated with a combination of pellets, DAP and lime after 90 days of the experiment. 2 gms combination of inputs treatment control ponds recorded a final mean fish weight of 10.00 gms in liner ponds, 8.84 gms and 8.41 gms in earthen and concrete ponds respectively (appendix 15). In the 4 gms combined inputs treatment control ponds, final mean weight of fish recorded after 90 days were 10.63 gms in liner ponds, 9.26 gms in earthen and 8.55 gms in concrete ponds. Final mean weight of fish in the 6 gms treatment control ponds were 10.99 gms in liner ponds, 9.93 gms and 9.27 gms in earthen and concrete ponds respectively.

Level three of inputs (6 gms) had better growth fish performance than 4 and 2 gms level of inputs possibly due to higher effect and more contribution of more minerals to the systems by increasing fertility, quality and more live feeds with 6 gms inputs compared to 4 and 2 gms level of inputs . The high production in concrete culture system compared to the other culture systems could therefore be attributed to, more phosphates, nitrates and other mineral content hence optimal and higher productivity in the concrete ponds compared to the other ponds. The higher pH and less suspended particles in the concrete ponds compared to the other culture systems could be attributed to the higher production recorded in the concrete ponds. These favourable conditions enhanced the process of photosynthesis increasing productivity of the concrete culture system leading to more available live feeds for fish hence higher fish production in the concrete ponds compared to the other ponds. Less suspended particles permitted penetration of more sunlight which is very vital for the process of photosynthesis hence increased phytoplankton activity increasing productivity. Addition of the combined inputs (lime, pellets and DAP) in the pond water increases primary productivity, decomposition hence increasing water fertility. Carbon dioxide content which is very vital for photosynthesis to take place could have been optimal increasing photosynthetic process especially in the concrete ponds. Natural productivity in the control ponds was minimal leading to less feeds in the pond water due to lower water fertility leading to lower recorded mean fish weights in the control ponds.

According to Karim, (2013) *Oreochromis niloticus* reared in fertilized and limed concrete ponds with 6 g of each and fish fed on 6 g commercial fish pellets twice daily, the fish attained a growth performance of 244.72 g in three months in Bangladesh. His results compare well but is higher than the recorded 35.35 g growth performance of fish in concrete ponds in the present study. In India in Krishna District, fish reared in limed and fertilized earthen ponds with 6 g of the inputs, a growth performance of 249.80 g was recorded, which is higher than that of the current study of 32.74 g in earthen ponds. Combined use of fertilizers, lime (6 g of each) and *Oreochromis niloticus* fed with 6 g commercial fish pellets of 30 % crude protein, the fish recorded a growth performance of 125.50 g in earthen ponds in Southern China (Liu and Wang, 2013). Their growth performance results are higher than that of 32.74 g in the current study.

4.7 Assessment of the level and factors influencing adoption of fish farming technologies in the study area

4.7.1 Socioeconomic characteristics of the respondents

Table 4.10: Descriptive statistics of the variables

Variable	(%)	Mean	S.D.	Minimum	Maximum
Age of household head	42	41.46	10.93	19	61
Gender household head	59	0.59	0.49	0	1
Marital status	83	0.83	0.38	0	1
Years of education	10	10.30	4.28	0	16
Size of household	3	2.80	1.67	0	7
Land size-ha	2	2.38	2.12	0.5	12
Annual farm income	20078	20077.78	21310.54	0	65000
Market access	90	0.90	0.30	0	1
Credit access (%)	46	0.46	0.49	0	1
Labour access (%)	22	0.22	0.48	0	2
Extension service	50	0.50	0.50	0	1

n-180

Socio-economic characteristics of the respondents showed marked variations after descriptive statistics of the variables were computed (Table 4.10). Average age of the household heads in the study area was 42 years. This average age compares well with other similar studies in aquaculture (e.g., Rozana, 2015; Ng *et al.*, 2013; Ahmed, 2009; Omar *et al.,* 2011; Gerard, 2012). The Kenya National Bureau of Statistics (KNBS, 2012) gives an estimate of the proportion of population in 15 – 64 age group as 54.9 percent, which is higher than the computed figure in the current study.

The male headed households constituted 59 percent in the selected sample and 41 % were female headed households. This presents an averagely equal gender representation in the collected data. Other similar studies in the region used varied gender proportions (Ayandiji and Oke, 2016), 71.8 percent males and 28.2 percent females in a similar study in Nigeria. Gender is an important factor in aquaculture production (Obisesan, 2014). About 83 percent of the respondents were married in the study (Table 4.10). According to Olaoye *et al.,* (2016), Ayandiji and Oke, (2016) marriage places family responsibilities on those who are married and for these responsibilities to be continually met, diversification of income generation activities are inevitable.

Most of the respondents in the study area had attained secondary education mean (10.30 years of education). Over 70 percent of respondents had gone past primary and secondary education. The Kenya National Bureau of Statistics (KNBS, 2012) gives a literacy rate of 53 percent in Meru County. Education influences respondents' attitudes and thoughts (Namara *et al.,* 2013; Waller *et al*., 2008). Mean size of household in the study area was about 3 people. Kenya National Bureau of Statistics (KNBS, 2012) reports a labour force of about one person working for a household. Similar findings were reported by (Suleiman, 2013; Okoruwa and Ogundele, 2006) in Nigeria.

Mean land size in the area of study was 2.38 acres (Table 4.10). Kenya National Bureau of Statistics reports a land holding size per household of 1.8 Ha for small scale and 18.25 Ha for large scale land owners (KNBS, 2012). Scarcity of land and increased population pressure result in intensification of production practices to increase land productivity of investments if intensification is to be profitable (Mwangi, 2015; Rozana, 2015; Fisher and Yates, 2014).

The average recorded annual farm income in the study area was about Ksh. 20,077 (Table 4.10). Kenya National Bureau of Statistics (KNBS, 2012) reports that, about 20 percent of the household income in the county comes from self-employment mainly from the agricultural sector and wage employment. This figure compares well with the Ksh 20,077 recorded in the study area. Annual farm income acts as an important strategy for overcoming credit challenges faced by the rural households in most developing countries (Reardon *et al*., 2007). Annual farm income acts as a substitute for borrowed funds in rural economies where credit markets are either dysfunctional or missing (Ellis and Freeman, 2004; Diiro, 2013). Annual farm income and employment are the twin decisive factors mostly used for determining the living standards of any region or community (Singha, 2012; Tapashi and Mithra, 2014).

About (90 percent) of the respondents had access to fish market in the study area (Table 4.10). Availability of market is critical for any enterprise or value chain to grow and promotes production of commodities because farmers produce with surety of marketing their commodities to better their livelihoods (Lowenberg, 2011; Peter, 2014).

About 46 percent of the respondents in the study area had access to credit facilities (Table 4.10) from micro-finance and other financial institutions. These credit facilities could be agricultural loan facilities from institutions notably Agricultural Finance Corporation, Faulu Kenya or cooperatives and micro-finance lending facilities in the county. Access to fish input credits promotes financial capacity of fish farmers reducing capital constraints as well as improving a household's-risk bearing ability and start-up funding is no longer a challenge (Mohamed and Temu, 2008; Simtowe and Zeller, 2006).

Labour availability in the study area was about 22 percent (Table 4.10). Implying that 22 percent of the total population in the county (about 330,000) are engaged in wage labour mainly in the agricultural sector in the County. Kenya National Bureau of Statistics (KNBS, 2012) reports that only 10 percent of the total population (about 135,630) are engaged for wage labour mainly in the agricultural sector in Meru County. The figure of 330,000 people engaged in labour in the county is therefore higher than the reported figure by Kenya National Bureau of Statistics of 135,630. High costs of inputs, hired labour, unavailability of demanded packages and untimely delivery are some of the main challenges facing most farmers in developing countries (Makokha *et al*., 2001; Ouma, 2006).

About 50 percent of the respondents were accessing extension services in the study area (Table 4.10). Availability of extension information and dissemination is key to the success of any agricultural enterprise (Rab, 2011; Banze, 2006). Development programs should focus more on information dissemination, training and monitoring visits (Pillay, 2006).

The study revealed Six (6) types of aquaculture technologies are practiced in the study area (Table 4.11). The use of liner technology was popular (22.55 %) while extensive (only pond water is fertilized, no feeding of fish) was the least adopted technology (6.82 %) (Table 4.11). In order of importance, Liner technology was therefore the most popular technology followed by rearing of male tilapia only, then earthen, intensive (feeding and fertilizing pond water), concrete and extensive was the least adopted

4.7.2 Fish farming technologies adopted by farmers in the study area

Table 4.11: Proportion of aquaculture technologies in the study area

Type of Technology	Percentage	Ranking
Intensive	14.25	4
Extensive	6.82	6
Liner	22.55	1
Concrete	13.24	5
Earthen	21.08	3
All Male Tilapia	22.06	2

technology (Table 4.11). Pond liners are applied where soils tend to be sandy and are not able to hold water for long. The preferred type of liners are those which are environmentally friendly, Ultra-Violet treated inorder to shield pond water from dangerous radiations. However in swampy and wetlands areas, liners are not applied. Extensive culture technology was the least popular in the study area (Table 4.11), possibly due to the fact that, most fish farmers have abandoned the technology, embracing modern technologies which result in high yield of fish. In extensive culture technology, there is fertilization of pond water and fish are not fed. Fish production from such systems is very low.

Ansah and Frimpond, (2015), Mwaniki, (2017) reported that, lining fish ponds using liners greatly conserves the water in ponds since there is no water loss through percolation and also water quality and cleanliness are improved. Liner colour preferred by most of the fish farmers in aquaculture is black colour. Black liners are good conductors or absorbers of heat and they also conceal fish from predators.

Variables influencing adoption of fish farming technologies in the study area showed marked variations after analysis of the eleven socioeconomic characteristics of the respondents using logit regression analysis (Table 4.12). The Marginal effects (Table 4.13) shows that annual farm income, market availability, credit availability, qualityextension services significantly ($p < 0.001$) influence the adoption of fish farming technologies in the study area. In order of importance, market availability had the strongest influence with a marginal effect of (1.066) followed by quality extension services (0.854), credit availability (0.830) and least was annual farm income (0.001). Various authors have advanced different factors that influence adoption of aquaculture technologies in different parts of the world (Rab, 2011). Gachucha *et al*., (2014) reported that extension agents provide farmers with adequate and appropriate information in order to make better decisions that helps them to optimize their use of

4.7.3 Determinants of adoption of fish farming technologies in the study area

Table 4.12: Determinants of adoption of fish farming technologies in the study area

Variable	Coefficients	S.E.	t-Test	p Values
Age of household head	0.074	0.062	1.200	0.232
Gender of household head	1.523	1.280	1.190	0.234
Marital status	0.655	1.145	0.570	0.567
Years of education	0.229	0.135	1.700	0.089
Size of household	0.344	0.368	0.930	0.350
Land size	0.027	0.186	0.140	0.885
Annual farm income	0.001	0.000	2.480	0.013***
Market access	4.273	1.614	2.650	0.008***
Credit access	3.327	1.173	2.840	0.005***
Labour availability	0.218	0.424	0.520	0.606
Extension service	3.425	1.344	2.550	0.011***
Constant	17.727	6.131	2.890	0.004
				n = 180

Note: *Significance at 5 %

Table 4.13: Marginal effects of the Logistic Regression model (level of adoption)

Variable	dy/dx	S.E.	t-Test	p -Values
Age of household head	0.019	0.015	1.200	0.231
Gender of household head	0.380	0.320	1.190	0.235
Marital status	0.163	0.286	0.570	0.567
Years of education	0.057	0.034	1.700	0.089
Size of household	0.086	0.092	0.930	0.351
Land size	0.007	0.046	0.140	0.885
Annual farm income	0.001	0.001	2.460	0.014***
Market access	1.066	0.406	2.620	0.009***
Credit access	0.830	0.294	2.820	0.005***
Labour availability	0.054	0.106	0.520	0.606
Extension service	0.854	0.328	2.600	0.009***

Note: *Significance at 5 % n = 180

limited resources. Fasikim, (2008) reported that extension services act as a major source for disseminating technical extension information to respondents especially the modern fish farming technologies and that poor extension service delivery is a serious constraint to aquaculture and agricultural production in general.

Salau *et al*., (2014) reported that availability of credit facilities enables a farmer to invest more in farm production and hence improves his/her ability to procure improved modern technologies. Credit facilities can also transform small scale fish farmers to commercial farmers because startup capital is no longer a constraint to the small-scale farmers. Access to credit facilities has been reported to stimulate new technologies adoption (Mohamed & Temu, 2008).

The marginal effect of market availability indicates that farmers are more likely ($p < 0.009$, Table 4.13) to adopt fish farming with an increase in accessibility of market for fish and fish products. This may be attributed to surety of farmers of selling the harvested fish to earn income and consequently enhance the household welfare.

Compared to other studies, Wetengere (2008); Stanley *et al.*, (2010) reported that fish farming technologies are acceptable if profitability arising from them is high compared to the existing practice. Provision of markets and cooperative societies or marketing networks can greatly influence the adoption of fish farming technologies (Ike and Roseline, 2007; Njankouawanji *et al.*, 2012).

Provision of extension services marginal effect ($p<0.009$) indicate that with increased provision of extension services, fish farmers adopt aquaculture technologies more (Table 4.13). This could be attributed to the fact that, extension services quickly equip the fish farmers with new effective ways of increasing fish production. Provision of extension services possibly also increases fish farmer's confidence and trust in fish farming due to the close guidance and instruction by qualified extension staff. Farmers therefore identify easily with the extension agents increasing adoption rate of the fish farming technologies.

Compared to other studies, Pillay, (2006) and Rab, (2011) reported that development programs should focus more on information dissemination, training and monitoring visits as means of transferring technologies on fish farming. According to Ohajianya *et al.,* (2007), factors such as extension educational contacts with fishermen, regularity of the contacts visits and provision of needed fisheries inputs are the main determinants for fishermen's adoption of modern technologies.

Provision of credit facility ($p<0.005$) influence adoption of fish farming technologies (Table 4.13). Fish farmers are more likely to adopt fish farming technologies with increase in provision of credit facilities. This may be attributed to the fact that, provision of credit facilities greatly enhances the farmers' financial capacity to procure expensive inputs like liners and quality fingerlings. Most farmers' dilemma is the source of adequate capital for initiating meaningful enterprises. Empowering them financially raises their morale to produce and readily adopt to new technologies (Jeffrey, 2007). Compared to other studies, Mwangi, (2015) reported that availability of credit facility strongly and significantly influenced the adoption of technologies in Kiambu, Kenya. Access to credit facilities promotes the adoption of risky technologies through relaxation of the liquidity challenges as well as through stimulation of household's-risk bearing ability (Simtowe and Zeller, 2006). There is therefore need for policy makers to improve current smallholder credit systems to ensure that a wider spectrum of smallholders are able to gain access to credit, specifically female-headed households (Koppel, 2009). This may, in certain cases, necessitate developing credit packages that are geared towards meeting the needs of specific target groups (Muzari *et al.*, 2013).

Kenyan government has started a program that offers free interest loans to youths and women (UWEZO fund) which has gone a long way in empowering women and enabling them to adopt agricultural technologies hence enhancing economic growth (Mwangi, 2015). Truong and Yamada, (2008), El – Sayed, (2006) and Itejika, (2007) while investigating the factors that influence the adoption of fish farming technologies in Malaysia, reported credit facility availability as one of the main factors playing a key role in adoption of fish farming technologies.

The marginal effect of annual farm income also indicates that with increase in annual farm income ($p<0.014$), fish farmers are more likely to adopt fish farming (Table 4.13). This may be attributed to the fact that, availability of annual income increases a farmer's financial capacity for investing in the farm enterprises, land preparation and procurement of inputs. Annual farm income availability also empowers the farmers financially and reduces their over reliance on borrowed loans or credits from financial institutions. Due to the increased financial capacity and empowerment, the farmers are thus more willing and capable of adopting fish farming technologies in the study area. Compared to other studies, Reardon *et al*., (2007) reported that farm income acts as an important strategy for overcoming credit challenges faced by the rural households in most developing countries. Annual farm income is reported to act as a replacement for loans in rural communities where credit facilities are inadequate, disorganized or are missing (Singha, 2012; Diiro, 2013).

CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.0 Summary of findings

The physico- chemical parameters in the three culture systems showed variations. The Temperatures ranged from 21.85 degrees Celsius in Concrete system to 25.72 degrees Celsius in the liner pond. The pH ranged from 8.04 in the Earthen pond to 9.47 in the Concrete pond. Concrete culture pond had the highest level of Dissolved Oxygen of 6.84 mg/l^{-1}, with 5.25 mg/l^{-1} in Liner with the lowest amount of dissolved Oxygen of 4.22 mg/l^{-1} in Earthen pond.

The effect of varying fish pellets quantities on growth performance of *Oreochromis niloticus* showed variations. The highest mean weight of 9.27±4.085gms was recorded in the earthen pond when fed with two grams of pellets, but when fed with 4 and 6 grams of pellets the highest mean weight of 8.43±2.645 and 11.82±0.006 was recorded in Liner and Concrete ponds respectively.

When the ponds were fertilized with varied quantities of inorganic DAP, the best performances was recorded in Concrete pond with mean growth of 7.62±0.12, 14.01±4.06 and 12.01±0.02 with 2, 4 and 6grams respectively. When the amount of lime was varied the best growth was in Concrete 7.37±0.01, with 4 gms lime.

The best growth performance was recorded in earthen pond 8.45±3.84 when 2 grams of Pellets, DAP and Lime was used again with 4grams of pellets, DAP and lime, the best growth performance was 8.08±1.91 in Earthen while with 6 grams of Pellets, DAP and Lime, the best growth of 11.78±4.31 was in the Concrete pond.

Level of adoption of aquaculture technologies was Liner 22.55% of those interviewed, Earthen 21.08% and Concrete 13.24%. The factors that influence adoption were market availability with a marginal effect dy/dx of 1.066, extension service 0.854, credit access 0.830, and annual farm income (0.001).

5.1 Conclusions

The physico-chemical parameters influenced growth performance of *Oreochromis niloticus*. In concrete culture system where dissolved oxygen and pH were highest, significant growth performance of tilapia was also recorded in this particular culture system. Liner and earthen ponds had less dissolved oxygen and pH than concrete ponds hence lower fish growth performance.

Varying fish pellets amounts showed no significant difference on the growth performance of tilapia. On varying DAP fertilizers and lime, there was significance difference in the growth performance of tilapia in the concrete culture system compared to the other ponds.

On combining the various input amounts, there was no significant difference in the growth performance of tilapia or mean weight gains. However highest total production was again recorded in the concrete culture system.

The factors identified influencing adoption and there order of importance were market access had the strongest influence, followed by extension services, credit access and annual farm income had the least influence. Level of adoption of aquaculture technologies was high in the study with liner pond technology being the most adopted and extensive technology the lowest.

5.2 Recommendations

Based on the physico - chemical parameters the concrete culture system is best due to the high dissolved oxygen and optimal pH which are crucial for optimum growth of fish and also for feeding. These physico – chemical parameters also resulted in very good performance of fish in the concrete pond compared to other culture systems. Fisheries managers and extension staff should therefore encourage fish farmers to adopt concrete fish culture to boost fish production and improve their livelihoods. The National and County government policy makers should come up with good water quality management policy on protection and conservation of all water bodies from pollution enhancing quality of life of all water organisms including fish.

Concrete culture system again showed a significant difference in the growth performance of fish when varied amounts of fertilizer and lime were used compared to the other culture systems. Concrete culture system is therefore the best in terms of fish production and it's more permanent with low maintenance compared to the other culture systems. In areas with poor soils which cannot retain water, fish farmers should therefore be encouraged to utilize concrete ponds to maximize production in their ponds. Technical officers in the field should therefore promote use of concrete ponds by fish farmers to increase fish production, livelihoods enhancing food security for the citizens. The second best culture system was earthen which showed good fish growth performance with low input amounts. It is cheaper to construct and good for areas with soils with high water retention especially swampy areas. Fisheries staff should therefore advise fish farmers to use such ponds in such areas to increase fish production from their ponds. Policy makers at National and County level should prepare a guiding policy on different kinds of fish production units, their viability, disadvantages and advantages and where and when they can be utilized by fish farmers to boost fish production.

Depending on the quantity of combined inputs, concrete culture system again resulted in the highest total production of fish compared to the other culture systems. Researchers and Fisheries personnel should therefore encourage fish farmers to utilize a combination of inputs in concrete culture systems to attain good fish production in aquaculture.

During planning, policy formulation and inception of projects and programmes in aquaculture and other fields, planners and programme managers should incorporate market access, extension services, credit access and annual farm income in programme implementation manuals to increase the success rate of projects and programmes. These crucial factors are also key in influencing adoption of technologies and ought to be taken seriously by managers and policy makers during introduction of new projects and programmes to farmers. Adoption of liner technology was high, however from the study, concrete ponds showed the best growth performance. Farmers should therefore be encouraged to start using concrete ponds which are more permanent with low maintenance. From experience, their construction costs are also not very different from that of liner ponds. On policy interventions, best practice demonstration sites for farmer education are necessary and should be established. National and County lead policy experts should therefore formulate a policy establishing departmental fish demonstration centres for training purposes for farmers, staff and researchers.

5.2.1 Recommendation for further research

(1) Only three culture systems were investigated in the study (earthen, liner and concrete). Growth performance of fish should also be investigated in other culture systems; cages, plastic tanks and raised ponds.

(2) *Oreochromis niloticus* was the only strain of tilapia whose growth performance was investigated in this study. Other strains and species of fish should also be researched on to assess their performance in different culture systems and conditions.

(3) Effect of other physico-chemical parameters turbidity, salinity and conductivity on the growth performance of different species of fish should also be carried out to expand the scope of research work.

(4) Market analysis and linkages, quality extension service and credit access analysis should be conducted along the entire aquaculture value chain to bridge the knowledge gaps in the sector.

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APPENDICES

APPENDIX 1: Average temperature (in degrees Celsius), pH and dissolved (DO in ml/l) recordings over the 90 day period in liner ponds between August 2015 and November 2015

POND NO	Temperature readings			pH readings			Dissolved oxygen		
	30 days	30-60	60-90	30days	30-60	60-90	30 days	30-60	60-90
4DL	26.08	27.04	23.71	8.44	8.48	8.26	4.97	4.66	4.91
3DL	27.13	26.74	23.99	8.44	8.54	7.85	4.51	4.83	4.83
2DL	26.02	26.64	23.79	8.45	8.48	7.99	5.66	5.66	5.81
1DL	26.01	26.66	23.71	8.46	8.46	7.93	5.74	5.79	5.79
4CL	26.03	26.71	23.71	8.41	8.58	8.01	5.21	5.21	5.27
3CL	26.01	26.72	23.93	8.43	8.51	8.43	5.13	5.23	5.23
1CL	27.13	26.66	24.15	8.44	8.44	7.90	5.38	5.38	5.44
4BL	26.04	26.98	23.88	8.44	8.58	8.44	5.11	5.16	5.16
2CL	27.05	26.73	23.65	8.46	8.46	7.95	5.18	5.18	5.24
3BL	26.86	26.90	24.14	8.33	8.46	8.33	4.88	4.93	4.93
2BL	27.24	26.81	23.42	8.34	8.60	7.89	5.23	5.23	5.30
1BL	26.93	26.88	23.78	8.44	8.44	8.44	4.82	4.86	4.86
1AL	27.05	26.84	24.22	8.38	8.52	7.95	5.32	5.32	5.38
2AL	26.07	26.89	23.60	8.35	8.53	8.35	4.83	4.89	4.89
3AL	27.17	26.75	23.68	8.49	8.49	8.14	5.61	5.61	5.67
4AL	26.05	26.96	23.55	8.44	8.50	7.70	5.07	5.20	5.27
Mean	26.55	26.81	23.81	8.42	8.50	8.10	5.17	5.20	5.25

APPENDIX 2: Average temperature (in degrees Celsius), pH and dissolved (DO in ml/l) recordings over the 90 day period in earthen ponds between August 2015 and November 2015

POND	Temperature readings			pH readings			Dissolved oxygen		
NO	30 days	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90
4DE	24.42	25.30	25.30	7.71	7.76	8.39	4.26	4.32	4.46
3DE	24.48	25.46	25.46	7.73	7.76	8.44	4.22	4.22	4.22
1DE	24.65	25.31	25.31	7.86	7.94	8.45	4.20	4.31	4.45
2CE	25.06	25.13	25.13	7.83	7.86	8.46	3.93	3.93	3.93
1CE	25.02	25.33	25.33	7.85	8.10	8.41	4.23	4.31	4.44
4AE	24.62	25.34	25.34	7.83	8.07	8.43	3.98	3.98	3.98
4BE	24.63	25.36	25.36	7.77	7.85	8.44	4.16	4.28	4.37
2AE	24.74	25.30	25.30	7.86	7.88	8.44	3.96	3.96	3.96
1AE	24.46	25.44	25.44	7.72	7.72	8.31	4.05	4.16	4.26
1BE	24.77	25.65	25.65	7.91	8.01	8.33	4.15	4.15	4.15
2BE	24.64	25.24	25.24	7.73	7.84	8.34	3.97	4.09	4.18
3BE	24.66	25.30	25.30	7.83	7.83	8.44	4.05	4.05	4.05
3AE	24.71	25.26	25.26	7.65	7.78	8.38	3.93	4.01	4.21
2DE	24.53	25.35	25.35	7.68	7.95	8.35	4.07	4.07	4.07
3CE	24.63	25.23	25.23	7.79	8.03	8.49	4.19	4.26	4.38
4CE	24.28	25.56	25.56	7.98	8.08	8.30	4.16	4.23	4.33
Mean	24.64	25.35	25.35	7.80	7.90	8.42	4.09	4.15	4.22

APPENDIX 3a: Average temperature (in degrees Celsius), pH and dissolved (DO in ml/l) recordings over the 90 day period in concrete ponds between August 2015 and November 2015

POND NO	Temperature readings			pH readings			Dissolved oxygen		
	30 days	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90
4DC	22.28	23.32	19.78	9.33	9.85	9.23	5.03	5.11	5.16
2DC	22.38	23.36	19.53	9.52	9.98	9.03	4.22	4.22	5.08
4CC	21.86	23.79	19.80	9.45	10.01	9.45	5.36	5.40	5.47
2CC	22.33	23.71	19.75	9.47	9.47	9.30	5.75	5.75	5.75
4BC	21.42	23.71	19.43	9.38	10.08	8.87	7.80	7.89	8.00
2BC	22.17	23.93	19.24	9.51	9.51	9.02	7.93	7.93	8.00
4AC	22.71	23.28	19.64	9.42	10.06	9.24	7.34	7.39	7.39
2AC	22.86	22.86	19.76	9.33	9.95	9.33	7.65	7.65	7.79
1AC	22.82	23.65	19.21	9.45	9.45	9.45	7.69	7.72	7.72
3AC	22.75	23.63	19.24	9.35	9.35	9.19	7.86	7.86	7.92
1BC	22.31	23.42	19.49	9.43	10.02	9.17	6.25	6.47	6.47
3BC	21.86	23.18	19.67	9.33	9.33	9.00	7.03	7.03	7.19
1CC	21.99	23.41	19.43	9.51	9.84	9.08	6.45	6.56	6.56
3CC	22.42	23.60	19.71	9.32	9.86	9.32	7.76	7.76	7.92
1DC	22.26	23.68	19.30	9.47	9.96	9.19	6.61	6.71	6.71
3DC	21.61	23.55	19.63	9.41	10.06	9.29	5.93	6.07	6.25
Mean	22.50	23.51	19.54	9.42	9.80	9.20	6.67	6.72	6.84

b. Mean daily pH values recorded in the three culture systems between August 2015 and November 2015

Culture systems	Mean daily pH values			
	30 days	60 days	90 days	Means
Liner ponds	8.42	8.50	8.10	8.35
Earthen ponds	7.80	7.90	8.42	8.04
Concrete ponds	9.42	9.80	9.20	9.47

c. Mean daily dissolved oxygen values recorded in the culture systems between August 2015 and November 2015

Culture systems	Mean daily dissolved oxygen values (mg L^{-1})		
	30 days	60 days	90 days
Liner ponds	5.17	5.20	5.25
Earthen ponds	4.09	4.15	4.22
Concrete ponds	6.67	6.72	6.84

APPENDIX 4: Physical chemical parameters (Temperature, Dissolved oxygen (DO) and PH in the different culture systems (Liner, Earthen and Concrete);

One-way ANOVA: 0-30 DaysTemp versus sites

```
Analysis of Variance for 0-30 Tem

Source    DF       SS       MS       F       P
sites      2  148.710   74.355  436.64   0.000
Error     45    7.663    0.170
Total     47  156.373
                             Individual 95% CIs For Mean
                             Based on Pooled StDev
Level      N     Mean    StDev  ----+---------+---------+---------+--
Concrete  16   22.252    0.424  (*-)
Earthen   16   24.644    0.200               (*-)
Liner p.  16   26.554    0.540                          (*)
                                ----+---------+---------+---------+--
Pooled StDev =    0.413           22.5      24.0      25.5      27.0
```

One-way ANOVA: 30-60 DaysTemp versus sites

```
Analysis of Variance for 30-60Tem
Source    DF       SS       MS       F       P
sites      2  87.6105  43.8052  1274.85   0.000
Error     45   1.5462   0.0344
Total     47  89.1567
                             Individual 95% CIs For Mean
Level      N     Mean    StDev  ------+---------+---------+---------+
Concrete  16   23.505    0.267  (*)
Earthen   16   25.348    0.128                 *)
Liner p.  16   26.807    0.124                            (*)
                                ------+---------+---------+---------+
Pooled StDev =    0.185            24.0      25.0      26.0      27.0
```

One-way ANOVA: 60-90 Days Temp. versus sites

```
Analysis of Variance for 60-90Tem
Source    DF       SS       MS       F       P
sites      2  289.8378  144.9189  3873.72   0.000
Error     45    1.6835    0.0374
Total     47  291.5213
                             Individual 95% CIs For Mean
                             Based on Pooled StDev
Level      N     Mean    StDev  ---+---------+---------+---------+---
Concrete  16   19.538    0.209  (*
Earthen   16   25.348    0.128                          (*
Liner p.  16   23.807    0.228                   *)
                                ---+---------+---------+---------+---
Pooled StDev =    0.193          20.0      22.0      24.0      26.0
```

One-way ANOVA: 0-30 Day DO versus sites

Analysis of Variance for 0-30 DO

```
Source     DF        SS        MS        F        P
sites       2    53.408    26.704    54.82    0.000
Error      45    21.920     0.487
Total      47    75.328
                               Individual 95% CIs For Mean
                               Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
Concrete   16    6.6663    1.1570                        (---*--)
Earthen    16    4.0944    0.1151  (---*--)
Liner p.   16    5.1656    0.3310           (---*--)
                                   ---+---------+---------+---------+---
Pooled StDev =   0.6979               4.0       5.0       6.0       7.0
```

One-way ANOVA: 30-60 Days DO versus sites

```
Analysis of Variance for 30-60 DO
Source     DF        SS        MS        F        P
sites       2    53.616    26.808    56.31    0.000
Error      45    21.425     0.476
Total      47    75.041
                               Individual 95% CIs For Mean
                               Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
Concrete   16    6.7200    1.1448                         (--*---)
Earthen    16    4.1456    0.1350   (--*---)
Liner p.   16    5.1963    0.3153           (---*--)

                                   ---+---------+---------+---------+---
```

One-way ANOVA: 60-90 Days DO versus sites

```
Analysis of Variance for 60-90 DO
Source     DF        SS        MS        F        P
sites       2    55.785    27.893    67.12    0.000
Error      45    18.701     0.416
Total      47    74.486
                               Individual 95% CIs For Mean
                               Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
Concrete   16    6.8363    1.0549                         (--*---)
Earthen    16    4.2150    0.1803   (--*--)
Liner p.   16    5.2488    0.3186           (--*---)
                                   --+---------+---------+---------+----
Pooled StDev =   0.6447              4.0       5.0       6.0       7.0
```

One-way ANOVA: 0-30 Days PH versus sites

```
Analysis of Variance for 0-30 PH
Source    DF        SS        MS        F        P
sites      2  21.41013  10.70506  2138.46    0.000
Error     45   0.22527   0.00501
Total     47  21.63540
                          Individual 95% CIs For Mean
                          Based on Pooled StDev
Level       N      Mean     StDev  -----+---------+---------+---------+-
Concrete   16    9.4175    0.0702                            *)
Earthen    16    7.7956    0.0890  (*)
Liner p.   16    8.4213    0.0466            *)
                                   -----+---------+---------+---------+-
Pooled StDev =   0.0708             8.00      8.50      9.00      9.50
```

One-way ANOVA: 30-60 Days PH versus sites

```
Analysis of Variance for 30-60 PH
Source    DF        SS        MS        F        P
sites      2   30.0116   15.0058   480.70    0.000
Error     45    1.4047    0.0312
Total     47   31.4164
                          Individual 95% CIs For Mean
                          Based on Pooled StDev
Level       N      Mean     StDev  ----------+---------+---------+------
Concrete   16    9.7988    0.2749                          (*-)
Earthen    16    7.9038    0.1247  (-*)
Liner p.   16    8.5044    0.0506          (-*)
                                   ----------+---------+---------+------
Pooled StDev =   0.1767                   8.40      9.00      9.60
```

One-way ANOVA: 60-90 Days PH versus sites

```
Analysis of Variance for 60-90 PH
Source    DF        SS        MS        F        P
sites      2   10.3334    5.1667   173.90    0.000
Error     45    1.3370    0.0297
Total     47   11.6704
                          Individual 95% CIs For Mean
                          Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
Concrete   16    9.1975    0.1638                          (--*-)
Earthen    16    8.4000    0.0584          (-*-)
Liner p.   16    8.0975    0.2427  (-*--)
                                   --+---------+---------+---------+----
Pooled StDev =   0.1724           8.05      8.40      8.75      9.10
```

APPENDIX 5a: Weight gain recordings in various culture systems on feeding *O.n* with different amounts of fish pellets between August and November 2015

Treatment	Pond No.	Initial weight	Wt. after 30 days	Wt. after 60 days	Wt.after 90 days	Mean	Total
2 gms Treatment of pellets	1AL	20.00	26.12	31.45	36.82	28.60	114.39
	1AE	20.00	24.55	36.18	47.80	32.13	128.53
	1AC	20.00	26.85	33.69	40.54	30.27	121.08
4 gms Treatment of pellets	1BL	20.00	25.42	35.34	45.34	31.54	126.14
	1BE	20.00	25.28	33.08	40.87	29.82	119.26
	1BC	20.00	26.64	34.24	40.83	30.44	121.76
6 gms Treatment of pellets	1CL	20.00	27.50	39.73	51.38	34.65	138.61
	1CE	20.00	29.16	40.48	51.79	35.37	141.46
	1CC	20.00	31.82	43.65	55.47	37.74	150.94

5b. Summary of mean weight gain within each culture system on feeding fish with 2, 4, and 6 grams fish pellets between August 2015 and November 2015

	Culture systems			***F*-value**	***P*-value**
2 gms fish pellets	**Liner**	**Earthen**	**Concrete**		
Mean weight gains (gms)	5.61 ± 0.445^{aA}	9.27 ± 4.085^{aA}	6.85 ± 0.006^{aA}	1.847	$p = 0.237$
4 gms fish pellets					
Mean weight gains (gms)	8.43 ± 2.645^{bA}	6.95 ± 1.469^{bA}	6.93 ± 0.583^{bA}	0.708	$p = 0.529$
6 gms fish pellets					
Mean weight gains (gms)	10.46 ± 2.580^{cA}	10.59 ± 1.262^{cA}	11.82 ± 0.006^{cB}	0.619	$p = 0.569$
F-value	3.862	1.496	215.015		
p - value	0.084	0.297	0.0001		

Values are expressed as mean ± SE. Values in the same row with different small letters in superscript are significantly different ($P \leq 0.05$). Values in same column with different upper cases in superscript are significantly different. Mean separated using LSD

APPENDIX 6: ANOVA tests for the weight gain after treatment with various amounts of pellets, DAP, lime and a combination of the inputs in various culture systems between August 2015 and November 2015

Weights at 2 gms of pellets

```
. oneway weightsvar1 culture
```

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	20.7896018	2	10.3948009	1.85	0.2371
Within groups	33.7665982	6	5.62776636		
Total	54.5562	8	6.819525		

Weights at 4 gms of pellets

```
. oneway wtat4gms culture
```

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	4.48062224	2	2.24031112	0.71	0.5296
Within groups	18.9855995	6	3.16426658		
Total	23.4662217	8	2.93327771		

Weights at 6 gms of pellets

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	3.40406614	2	1.70203307	0.62	0.5696
Within groups	16.4935306	6	2.74892177		
Total	19.8975968	8	2.4871996		

2gms DAP

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	3.07368976	2	1.53684488	0.83	0.4799
Within groups	11.0844663	6	1.84741105		
Total	14.1581561	8	1.76976951		

4gms DAP

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	234.282968	2	117.141484	20.07	0.0022
Within groups	35.0238065	6	5.83730108		
Total	269.306774	8	33.6633468		

6 gms DAP

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	14.222866	2	7.11143299	1.50	0.2960
Within groups	28.4147323	6	4.73578871		
Total	42.6375983	8	5.32969978		

2gms Lime

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	19.6952899	2	9.84764493	3.44	0.1010
Within groups	17.1636013	6	2.86060021		
Total	36.8588911	8	4.60736139		

4gms Lime

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	7.76646767	2	3.88323384	5.18	0.0493
Within groups	4.4957336	6	.749288934		
Total	12.2622013	8	1.53277516		

6gms Lime

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	48.8718053	2	24.4359026	2.91	0.1307
Within groups	50.366398	6	8.39439966		
Total	99.2382033	8	12.4047754		

Combination of inputs (2gms of each)

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	6.52695574	2	3.26347787	0.53	0.6142
Within groups	36.9910676	6	6.16517793		
Total	43.5180233	8	5.43975292		

Combination of inputs (4 gms of each)

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	22.456422	2	11.228211	2.86	0.1340
Within groups	23.536133	6	3.92268883		
Total	45.992555	8	5.74906937		

Combination of inputs (6gms of each)

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	1.18548914	2	.592744568	0.09	0.9115
Within groups	37.7940017	6	6.29900029		
Total	38.9794909	8	4.87243636		

APPENDIX 7: Weight gain readings in various culture systems when the pond water was treated with varying amounts of DAP between August 2015 and November 2015

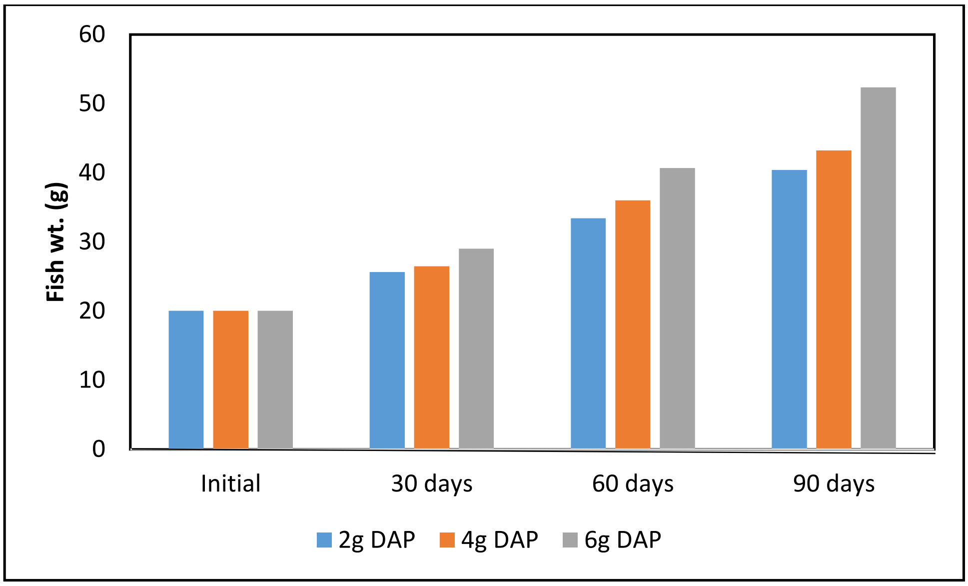
Treatment	Pond No.	Initial weight	Wt. after 30 days	Wt. after 60 days	Wt.after 90 days	Mean	Total
2 gms Treatment with DAP	2AL	20.00	24.87	33.16	39.31	29.34	117.36
	2AE	20.00	24.52	31.77	39.01	28.83	115.32
	2AC	20.00	27.57	35.32	42.87	31.45	125.78
4 gms Treatment with DAP	2BL	20.00	21.05	22.80	24.60	22.13	88.50
	2BE	20.00	26.63	34.80	42.96	31.11	124.44
	2BC	20.00	31.68	50.38	62.05	41.03	164.12
6 gms Treatment with DAP	2CL	20.00	27.10	40.50	53.83	35.36	141.43
	2CE	20.00	27.85	37.52	47.18	33.14	132.57
	2CC	20.00	32.02	44.05	56.05	38.04	152.14

APPENDIX 8: Table of summary of mean weight gain of fish in (gms) against time in days on fertilizing pond water with varying amounts of DAP during the study period

Treatment	Culture systems			***F-value***	***P*-value**
30	**Liner**	**Earthen**	**Concrete**		
Mean weight gains (g)	6.430 ± 1.737^{aA}	6.330 ± 1.585^{aA}	7.617 ± 0.115^{aA}	2.904	*p* = 0.131
60					
Mean weight gains (g)	1.517 ± 0.448^{bA}	7.637 ± 0.915^{bA}	14.013 ± 4.059^{bB}	0.187	*p* = 0.384
90					
Mean weight gains (g)	11.277 ± 3.617^{cB}	9.053 ± 1.059^{cA}	12.010 ± 0.173^{cAB}	1.568	*p* = 0.283
F-value	13.147	3.734	5.844		
p - value	0.006	0.088	0.039		

Values are expressed as mean ± SE. Values in the same row with different small letters in superscript are significantly different ($P \leq 0.05$). Values in same column with different upper cases in superscript are significantly different. Mean separated using LSD

APPENDIX 9: Weight gains when pond water was treated with 2 gms, 4 gms and 6 gms DAP in various culture systems between August 2015 and November 2015



APPENDIX 10: Weight gain recordings in various culture systems after treating pond water with varying amounts of lime between August 2015 and November 2015

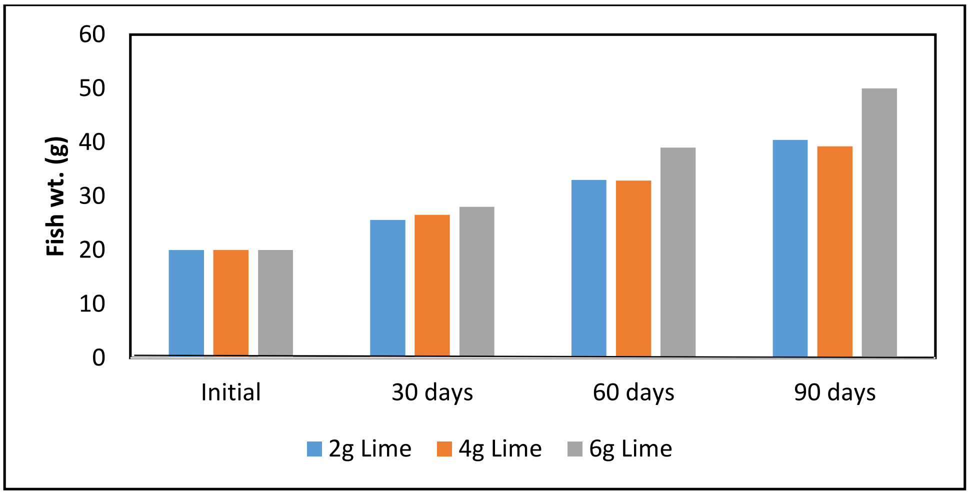
Treatment	Pond No.	Initial weight	Wt. after 30 days	Wt. after 60 days	Wt.after 90 days	Mean	Total
2 gms Treatment with lime	3AL	20.00	25.53	36.03	46.63	32.06	128.22
	3AE	20.00	25.13	30.75	36.36	28.06	112.24
	3AC	20.00	26.14	32.24	38.35	29.19	116.76
4 gms Treatment with lime	3BL	20.00	26.53	31.03	35.48	28.27	113.07
	3BE	20.00	25.66	32.91	40.15	29.69	118.76
	3BC	20.00	27.40	34.78	42.14	31.09	124.36
6 gms Treatment with lime	3CL	20.00	21.81	32.39	42.79	29.25	117.00
	3CE	20.00	29.18	38.43	47.67	33.83	135.31
	3CC	20.00	33.16	46.31	59.45	39.74	158.94

Appendix 11: Table of Summary of mean weight gain of fish in each culture system against time on treating pond water with varying amounts of lime during the study period.

Days	Culture systems			*F-value*	*P*-value
30	**Liner**	**Earthen**	**Concrete**		
Mean weight gain (g)	8.867±2.9167^{aA}	5.453±0.280^{aA}	6.107±0.006^{aA}	3.443	0.101
60					
Mean weight gain (g)	5.15±1.169^{bA}	6.703±0.938^{bA}	7.367±0.011^{bB}	5.183	0.049*
90					
Mean weight gain (g)	7.59±5.018^{cA}	9.213±0.055^{cB}	13,143±0.006^{cAC}	2.911	0.131
F-value	0.916	34.315	633541.167		
p - value	0.450	0.001	0.0001		

Values are expressed as mean ± SE. Values in the same row with different small letters in superscript are significantly different ($P \leq 0.05$). Values in same column with different upper cases in superscript are significantly different. Mean separated using LSD

APPENDIX 12: Weight gains after treating pond water with varying amounts of lime between August 2015 and November 2015



APPENDIX 13: Weight gain recordings when the culture systems were treated with a combination of Pellets, DAP and Lime between August 2015 and November 2015

Treatment	Pond No.	Initial weight	Wt. after 30 days	Wt. after 60 days	Wt.after 90 days	Mean	Total
2 gms lime, DAP and pellets	4AL	20.02	24.25	31.90	39.40	28.89	115.57
	4AE	20.01	24.51	36.68	45.36	31.64	126.56
	4AC	20.00	27.93	36.06	43.99	32.00	127.98
4 gms lime, DAP and pellets	4BL	20.02	21.39	27.77	34.00	25.8	103.18
	4BE	20.00	25.88	35.07	44.25	31.3	125.72
	4BC	20.03	27.93	35.93	43.83	31.93	127.72
6 gms lime, DAP and pellets	4CL	20.03	26.88	41.69	55.38	36	143.98
	4CE	20.02	30.27	41.52	52.76	36.14	144.57
	4CC	20.03	31.54	43.04	54.55	37.29	149.16

APPENDIX 14: Recordings of weight of fish in the control ponds between August 2015 and November 2015 – Pellets treatment

Pellets treatment	Wt of fish (gms) after 30 days	60 days	90 days	Average	Total
C1AL	13.01	8.05	6.04	9.03	27.10
C1AE	12.05	7.99	6.05	8.70	26.09
C1AC	10.09	7.01	5.09	7.40	22.19
C1BL	12.05	7.79	6.02	8.62	25.86
C1BE	10.89	7.01	5.99	7.96	23.89
C1BC	11.05	6.69	5.59	7.78	23.33
C1CL	13.22	8.01	6.68	9.30	27.91
C1CE	11.84	6.94	5.87	8.22	24.65
C1CC	9.75	6.01	5.41	7.06	21.17

APPENDIX 15: Recordings of weight of fish in the control ponds between August 2015 and November 2015 – DAP treatment

DAP treatment	Wt of fish (gms) after 30 days	60 days	90 days	Average	Total
C2AL	10.03	7.79	6.01	7.94	23.83
C2AE	10.01	8.01	6.68	8.23	24.70
C2AC	9.95	7.79	5.95	7.90	23.69
C2BL	11.99	8.01	6.67	8.89	26.67
C2BE	13.04	8.69	6.05	9.26	27.78
C2BE	10.99	6.65	5.88	7.84	23.52
C2CL	14.01	9.76	6.68	10.15	30.45
C2CE	12.45	8.01	6.01	8.82	26.47
C2CC	11.89	6.95	5.99	8.28	24.83

APPENDIX 16: Recordings of weight of fish in the control ponds between August 2015 and November 2015 – Lime treatment

Lime treatment	Wt of fish (gms) after 30 days	60 days	90 days	Average	Total
C3AL	13.22	9.11	5.98	9.44	28.31
C3AE	14.11	9.69	6.01	9.94	29.81
C3AC	12.99	8.44	5.01	8.81	26.44
C3BL	12.99	8.79	6.03	9.27	27.81
C3BE	13.23	7.99	5.89	9.04	27.11
C3BC	11.99	5.58	4.99	7.52	22.56
C3CL	15.01	10.05	6.77	10.61	31.83
C3CE	13.89	8.55	4.99	9.14	27.43
C3CC	12.79	8.69	4.77	8.75	26.25

APPENDIX 17: Recordings of weight of fish in the control ponds between August 2015 and November 2015 – Combination of inputs

Combination of inputs treatment	Wt of fish (gms) after 30 days	60 days	90 days	Average	Total
C4AL	14.45	9.01	6.55	10.00	30.01
C4AE	12.56	7.98	5.98	8.84	26.52
C4AC	12.24	7.01	5.99	8.41	25.24
C4BL	13.55	10.45	7.89	10.63	31.89
C4BE	12.99	9.01	5.77	9.26	27.77
C4BC	11.99	8.65	5.01	8.55	25.65
C4CL	15.09	10.99	6.89	10.99	32.97
C4CE	13.98	9.75	6.05	9.93	29.78
C4CC	12.95	8.88	5.98	9.27	27.81

APPENDIX 18: Overall mean weight gains in the culture systems between August 2015 and November 2015 in the various culture systems

Overall mean wt gains	Liner	Earthen	Concrete	F =Value	P - Value
Feed treatment	8.18	8.94	8.53	0.08	0.92
STD	±1.84	±1.84	±2.85		
DAP treatment	6.41	7.67	11.21	1.54	0.29
STD	±4.88	±1.36	±3.27		
Lime treatment	7.20	7.12	8.87	0.41	0.67
STD	±1.89	±1.91	±3.75		
Combination of inputs	7.63	9.14	9.15	0.34	0.72
STD	±3.7	±1.54	±2.05		
F - Value	0.14	1.02	0.47		
P - Value	0.93	0.43	0.71		

APPENDIX 19a: Questionnaire. To identify the factors that influence the adoption of fish farming technologies.

This questionnaire attempts to research on the factors that influence the adoption of fish farming technologies in the study area. The information will be treated with total confidentiality and used for research purposes only. Please complete every item as honestly as possible and make comments where necessary. You may not give your name in the questionnaire for confidentiality purposes.

SECTION A: SOCIAL ECONOMIC

1.Please indicate your age in the bracket

a) Below 25 years ☐ b) 26 – 35 ☐ c) 36 -45 ☐ d) Above 45 ☐

b) Gender, Male ☐ Female ☐

2. Marital Status. Please tick.

(i) (a) Married ☐ b) Not married ☐ (ii) Gender (a) Male ☐ (b) Female ☐

3. Level of Education (please tick)

a) Primary 8 (b) Secondary 12 (c) College 14 (d) University 16 (e) Other 18

4. Size of household (please tick)

(a) 1 ☐ (b) 2 ☐ (c) 3 ☐ (d) 4 ☐ (e) 5 ☐ (f) 6 ☐ (g) 7 ☐

5. Size of your land in acres

(a) 0.5 ☐ (b) 1 ☐ (c) 3 ☐ (d) 4 ☐ (e) 5 ☐ (f) 6 ☐ (g) 7 ☐ (h) 9 ☐ (i) 1☐

6. Do you keep fish in your farm? Yes ☐ No ☐

7. If yes, what species do you rear? a) Tilapia ☐ b) Clarias ☐ c) Trout ☐ (d) Common carp ☐ e) Goldfish ☐

SECTION B: FISH FARMING TECHNOLOGIES ADOPTION

8. Out of the following fish farming technologies, please tick the ones which are found in your area since 2009;

a) Intensive culture (Inorganic feeds, fertilization of pond and liming) ☐

b) Extensive culture (Fertilization of pond, no feeding) ☐

c) Liner ponds ☐

d) Concrete ponds ☐

e) Earthen ponds ☐

f) Use of monosex (all male tilapia) ☐

g) Use of other faster growing species for example catfish ☐

9. Of the above fish farming technologies, which one have you adopted in your farm?

a) Intensive culture (Inorganic feeds, fertilization of pond and liming) ☐

b) Extensive culture (Fertilization of pond, no feeding) ☐

c) Liner ponds ☐

d) Concrete ponds ☐

e) Earthen ponds ☐

f) Use of monosex (all male tilapia) ☐

g) Use of faster growing species for example catfish ☐

10. (a) What is your estimated annual income from fish farming?

(b) What is your estimated annual income from other sources other than fish farming?

11. What factors influence the adoption of fish farming technologies by farmers in your county? Please start with the factor with the highest influence. ((Chose from;

1.quality seed and feed, 2.market, 3.land availability and 4.water availability, 5. Quality extension service, 6. Credit facilities and labour availability).

i ………………………………………………………………………Very high

ii……………………………………………………………………….High

iii………………………………………………………………………Average

iv………………………………………………………………………Low

v……………………………………………………………………..Very low

vi…………………………………………………………………………None

SECTION C: LABOUR, CREDIT FACILITIES AND MARKET AVAILABILITY

12. What are the market outlets for your fish in your area?

a) Pond site ☐ b) Local market ☐ c) Hotels ☐ d) None ☐

13. Is market for agriculture produce available in your area? Yes ☐ NO ☐

14.What is the impact of market availability on fish farming adoption?

a) Very high ☐ b) high ☐ c) moderate ☐ d) low ☐

15.Are there any credit facilities available in your area? Yes ☐ No ☐

16. What impact would provision of credit facilities have on fish farming?

a) Very high ☐ b) high ☐ c) moderate ☐ d) low ☐

17.How many people have you employed in your farm?

a) 1 ☐ b) 2 ☐ c) 3 ☐ d) None ☐

SECTION C: ENVIRONMENTAL

18. Are extension services available in your area? Yes ☐ NO ☐

19. How many trees were cut during fish pond construction on your farm?

a) None ☐ b) 1 – 5 ☐ c) 6 – 10 ☐ d) More than 10 ☐

20. How many trees did you plant on your farm after construction of your pond(s)?

APPENDIX 20: Selected plates of photos of various activities at the study area

Plate 1: Recording weight of fish at the study area

Plate 2: Some of the 2 X 1m ponds after stocking, secured with a netting material

Plate 3: Illustration of labeling of the various types of culture systems (fish ponds)

Plate 4: The site was fenced with strong chicken wire mesh, to keep off predators

Plate 5: Entrance to the study site showing a Signboard of the fisheries offices