UNIVERSITY OF CAPE COAST

SCHOOL OF BIOLOGICAL SCIENCES

OBSERVATIONS ON THE GROWTH AND SURVIVAL OF *Oreochromis niloticus* (L) FED ON FORMULATED FEEDS

BY

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DECLARATION

Candidate's Declaration

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

……... **…....……**

LAWRENCE ARMAH AHIAH **DATE**

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

…… **……..**

PROF. JOHN BLAY, JR. **DATE**

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ABSTRACT

Five feeds, designated A, B, C, D and E, were used in the culture of *Oreochromis niloticus* (L) to evaluate and compare their effects on growth performance, feed conversion ratio (FCR), fish production, survival rate and profitability in commercial tilapia farming in Ghana. Feed A contained only wheat bran and was used as the control; Feeds B, C and E were formulated from wheat bran, fishmeal, maize, palm oil and premix vitamins in varied proportions. Feed D was a commercial fish feed from Ghana Agro-Food Processing Company (GAFCO). The study was conducted in fifteen 6-m^3 hapas mounted in a 2,000 m^2 earthen pond. Each hapa was stocked with thirty *O. niloticus* fingerlings of an average weight of 40 g and were fed on the various experimental feeds (in triplicates) for 168 days.

Fish fed Feed E had significantly ($P < 0.5$) higher final weight (267.2 ± 2.12 g), survival rate (93.3 ± 1.93 %), absolute growth rate (1.32 ± 0.02 g/day), specific growth rate (1.06 ± 0.04 %), production (6.26 ± 0.37 kg) and lower FCR (2.46 ± 0.08) than any of those given Feeds A (control), B, C and D. The final weights of fish given Feeds B, C and D were significantly ($P < 0.5$) higher than the weight of fish fed on the control. The sale of fish fed Feed E accrued significantly ($P < 0.05$) higher profit (GH¢ 14.78) than any of the fish given Feeds A, B, C and D.

It was concluded that Feed E induced superior growth performance, converted more efficiently into fish flesh, exhibited good floating ability and was therefore, more economical for commercial tilapia farming in Ghana.

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DEDICATION

To my wife, Mrs Jackline Ahia-Armah and daughters, Morishita, Monalisa, Yukero and Yukiko Ahia-Armah.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER ONE

INTRODUCTION

Background

Fish farming started in Ghana in the 1950s (MacPherson and Agyenim-Boateng, 1991). As at now there has not been a progressive development in the industry. The main constraints to aquaculture development in Ghana according to Balarin (1998) included lack of adequate and healthy fingerlings, lack of suppliers and manufacturers of quality fish feed for efficient production, lack of adequate fishpond management skills and poor pond construction techniques among others.

The Directorate of Fisheries had, through several programmes and projects, succeeded in producing healthy fingerlings for farmers and also trained farmers in fishpond construction and management skills. Currently, fish farmers are periodically given in-service training to equip them with modern skills in fish husbandry, harvesting and disease management.

However, the non-availability of quality commercial fish feed for the fish farming industry is still hampering the progressive development of aquaculture in Ghana. The poultry industry in Ghana is doing well simply because there are commercial poultry feeds on the market for prospective poultry farmers.

Aquaculture is currently the fastest growing animal production sector in the world, expanding at an average annual rate of about 11 % since 1984 (Wing-Keong,

2002). Aquaculture production is expected to continue to increase at a rapid pace to meet the demands of the growing human population and to compensate for the shortfall in the capture fisheries resource which is highly over-exploited. This projected increase in aquaculture production must be supported by a corresponding increase in the production of formulated diets for the culture organisms. Artificially formulated diets (aquafeed) play a crucial role in sustaining the expansion of aquaculture production, mainly because feed can make up 50 % or more of the production cost of most aquaculture systems (Wing-Keong, 2002). Poor and unbalanced feeds given to fish usually result in stunted growth; fish becomes small and skinny. Such fish are unattractive, resulting in poor prices, hence low or no profits are made on them.

Most fish farmers do not even feed their fish whilst others depend on poultry or pig manure as indirect feed to boost primary productivity in the ponds. Most commercial fish farmers usually use a trial-and-error kind of feed preparation and often the crude protein present in such feeds is not known. The problem of deficiencies in the nutrition of fish stocks in semi-intensive aquaculture practices is the least addressed aspect of the industry (De Silva, 1993).

The emerging commercial fish farms in Ghana do not have ready-made fish feed on the market. Most fish farmers formulate their own feeds. For instance, Tropo Farms in Asutsuare and Crystal Lake Fisheries formulate their own feeds after going through trial-and-error formulations (Personal observation). Their formulae are not available to other fish farmers.

In recent times (August, 2005), Ghana Agro-Food Processing Company, GAFCO introduced a tilapia feed onto the market for prospective fish farmers. This

seems to be a breakthrough for the industry. However, the quality of the feed leaves much to be desired. For instance, the pelleted feed sinks very fast to the bottom of the pond and is too hard for the fish to swallow or nip at. Furthermore, the protein content is only about 18.5 %, which is quite low. This is a clear indication that more research has to be done on fish feeds by the feed manufacturers. However, Mr. Sedo of GAFCO (personal communication) has indicated that their tilapia feed has the following composition: Moisture 11 %, Protein 30 %, Fat 8 %, Ash 10 % and Fibre 7-8 %. Therefore, the GAFCO feed was chosen as one of the experimental feeds to assess its performance on tilapia.

It has been established that fishes require about two to four times more dietary protein than warm-blooded animals like birds and mammals (Jauncey, 1998). It has been documented by Cho *et al*. (1985) and National Research Council (1981, 1983) that the optimal protein level for *Tilapia nilotica (Oreochromis niloticus* (L) ranges from 30 to 35 % when both sexes are raised together.

Werner (1989) reported that growth takes place when the quantity of food ingested exceeds that required for the maintenance of the body. Feed supplies the energy for growth and other body processes such as breathing, digestion, swimming, and reproduction. Some of these functions are of higher priority than the others. Thus, if feed supply is limited, some very important body processes suffer. The energy from the feed is first used for breathing and digestion; swimming to catch feed is next, followed by reproduction, then growth. Thus, unless fish is well fed in an ideal environment, growth will be affected negatively. The growth rate of the fish and the factors influencing it are most important to fish farmers to ensure good profit.

Tilapias are now one of the most important groups of aquaculture species; production increased significantly around 1991-2001 with a record of almost 1.5 million tonnes in 2001 (FAO, 2002). Tilapia exhibit their best growth rates when they are fed a balanced diet that provides a proper mix of protein, carbohydrates, lipids, vitamins, mineral and fiber. Jauncey and Ross (1982), El-Sayed and Teshima (1991) and Stickney (1996) provide excellent reviews that examine the details of tilapia nutrition. The nutritional requirements are slightly different for each species and more importantly vary with age of the fish. Fry and fingerlings require a diet higher in protein, lipids, vitamins and minerals and lower in carbohydrates when they are developing muscle, internal organs and bone during rapid growth phase. Sub-adult fish need more calories from fat and carbohydrates for basal metabolism and a smaller percentage of protein for growth. But the absolute amount of food the fish eats will still be increasing as the fish grows larger. Adult fish need even less protein. However, the amino acids that make up that protein need to be available in certain ratios. Feed formulators adjust protein sources to fit the amino acid requirements in the growth cycle. Brood fish require high protein and fat levels to increase reproductive efficiency (Santiago *et al*., 1985; Chang *et al*., 1988).

In response to the increased cost of land and labour, as well as increased demand for fish nowadays, tilapia husbandry requires fish farmers to stock at densities higher than could be supported by the natural nutrient sources. The use of feeds in aquaculture systems has increased production and profits considerably. Quality and quantity are the major factors determining profitability, since feed represents the largest single expenditure in semi-intensive and intensive culture operations. For instance, fish feeds

are expensive and can amount to 50 % or more of the variable cost of most fish culture operations. Thus, economical production depends on availability of least-cost, nutritionally-balanced diets (Cesar and Darryl, 2000).

Most research on tilapia feed had focused on the utilization of lower-cost by-product materials. Several sources of plant proteins as substitutes for the more expensive fish meal, partially or completely, have been experimented on various finfish. Plant proteins examined have included soybean meal (Quartararo *et al*., 1998), cacao husks (Pouomogne *et al*., 1997) various cereals (Al-Ogaily *et al*., 1996), brewery draff (Pouomogne *et al*., 1992), napier grass (Chikafumbwa, 1996) and cottonseed meal (Robinson *et al*., 1984a, b; El-Sayed 1990). For tilapia diets, typical plant protein alternatives have included soybean meal (Brandt 1979; Jackson *et al*., 1982) and sunflower seed meal (Jackson *et al*., 1982) among others. However, due to the presence of some anti-nutritional factors, most of these ingredients can only be used in tilapia feed after prior treatments (Antoine *et al*., 1987; Olvera-Novoa *et al*., 1990; Yousif *et al*., 1994). Results from the use of these plant proteins show a range from high growth and survival in some species to poor growth and survival in others.

Feeding ecology of tilapia

One of the keys to successful fish culture is the understanding of some biological fundamentals, especially food and feeding behaviour, of fish. Understanding the natural feeding ecology of tilapia is of paramount importance for suitable formulation of pelleted diets and feeding regimes designed for fish culture systems (Jauncey 1998).

Tilapias are predominantly herbivorous, which means they are able to produce high quality protein, suitable for human consumption from less protein sources (Jauncey and Ross, 1982). The characteristic diet of an adult tilapia is plant matter or detritus of plant origin. Blue-green and green algae, diatoms, macrophytes and amorphous detritus are all common dietary components of tilapia (Chapman and Fernando, 1994). According to Bowen (1982), tilapia may consume animal material but it does not constitute significant proportion of the total food ingested. The juvenile tilapia feed on phytoplankton and small invertebrates especially crustacea (Le Roux, 1956; Northcott *et al*., 1991). Tudorancea *et al*. (1988) and Abdel-Tawwab (2000) reported that *O. niloticus* is phytoplanktivore and a facultative detritivore fish. Anibeze (2001) also found out that *O. niloticus* in Agulu Lake basin in Nigeria fed mainly on a wide variety of phytoplankton and zooplankton. Bowen (1978) reported that there is a positive correlation between tilapia length and the depth at which they feed. This was thought to be related to temperature, with the juvenile tilapia feeding in shallower and warmer areas and the adults feeding in deeper and cooler waters.

In general, *Sarotherodon* and *Oreochromis* are primarily omnivores taking phytoplankton, periphyton or detritus whilst those of the genus *Tilapia* tend to take coarser food including macrophytes and are consequently used to control weed growth in irrigation channels, ponds and dams (Juancey, 1998). In addition to grazing on phytoplankton (Moriarty and Moriarty, 1973), tilapia feed on benthic, attached algal and detrital aggregates (Bowen, 1981, 1982). It has been argued that tilapias are perhaps the only true herbivorous fishes (Bitterlich and Gnaiger, 1984). This was because the content of the guts of naturally feeding *Oreochromis* and *Sarotherodon* species comprise

mainly algae and algal derived detritus (De Silva *et al*., 1984; Khallaf and Alme-na-ei, 1987). Dempster *et al*., (1993, 1995) demonstrated that *Oreochromis niloticus* could graze efficiently on periphyton, the community of microscopic plants and animals that attaches itself to surfaces of stones and plants.

Despite tilapias exhibiting a high degree of morphological specialization with respect to feeding, they also show a high degree of plasticity in feeding behaviour and opportunism with respect to diet which has undoubtedly been one of the keys to success of these species as colonizers (McKaye and Marsh, 1983; Getachew, 1987; Bluhdorn *et al*., 1990; Liem, 1991; Yamaoka, 1991; Piyasiri and Perera, 2001).

Feeding organs and digestive tract of *O. niloticus*

The feeding organs of tilapia are simple and unspecialized (Bowen, 1982). Tilapia has two types of teeth, those on the jaw and those borne on the pharyngeal bone. The teeth of different species vary in accordance with the preferred diet ranging from unicellular algae and bacteria to coarse vegetation (Trewavas, 1982). Teeth of the jaw are small unicuspid, bicuspid or tricuspid occurring in one to five rows and may be flattened distally to form blades, useful as scrapers (Fryer and Isles, 1972: Lanzing and Higginbottom, 1976). According to Jauncey (1998), the differences in dentition of tilapia influence the acceptability of food materials of varying sizes, hardness and texture and thus should be taken into consideration when preparing artificial diets for *O. niloticus*. For instance, the dentition of the pharyngeal teeth of the phytoplanktivorous *Sarotherodon esculentus* are fine, thin hooked structures whereas those of *Tilapia*

rendalli, a macrophyte consumer, are coarse and robust (Fryer and Isles, 1972; Caulton, 1976).

The role of pharyngeal apparatus is to prepare the food for digestion by shredding coarser materials and breaking the cell walls before passing the food on to the stomach. The oesophagus is short with a small diameter leading to a small sac-like stomach, which plays a gastric function and is separated from the intestine by a sphincter. Immediately, behind the pyloric sphincter is a bile duct which opens into the intestine. The intestine is divided into an anterior short, thin walled, duodenum and a very long posterior section, which has a smaller diameter (Bowen, 1982). The length of the entire intestine of a tilapia is between 5 to 8 times the total length of the fish (Caulton, 1976; Pauly, 1976; Ross and Jauncey, 1981).

Digestion in *O. niloticus*

In *O. niloticus,* the teeth are used to shred coarser food materials and breakdown some cell walls before passing it on to the stomach. The maceration of the food increases its surface area thereby facilitating the enzyme-substrate interaction in the stomach. Food from the buccal cavity goes through the short oesophagus to a sac-like stomach. The pH of the stomach fluid of an actively digesting tilapia is as low as 1.25 (Moriarty, 1973; Bowen, 1976; Caulton, 1976) and values as low as 1.0 have been recorded (Payne, 1978). This low stomach pH appears to be typical to tilapia, as the gastric pH of other fish is usually greater than 2.0 (Barrington, 1957; Smit, 1968; Lobel, 1980; Bowen, 1981). The acid in the stomach breaks down cellulose and lyses blue-green algal walls which make subsequent intestinal digestion possible by allowing

enzymes access to the algal cell contents (Moriarty, 1973). At the end of the daily feeding period the secretion of gastric acid decreases and the stomach pH returns to 5-7. The secretion of acid in the stomach is usually triggered by the process of feeding and filling of the stomach with food (Jauncey, 1998).

The partially digested food from the stomach is passed on to the thin walled intestine which tapers gradually from the pyloric sphincter. Further digestion of food and assimilation occurs in the intestines where the common bile duct adds bile salts to maintain the pH at 6.8-8.8 (Fish, 1960; Nagase, 1964). Jauncey (1998) suggested that a good understanding of the natural feeding habits and digestive capabilities of *O. niloticus* could be used by food technologist to help produce a nutritionally balanced and acceptable diet for tilapia.

Tilapia digest protein in natural food and in commercial feeds into amino acids, which are then absorbed in the gut, transported in the blood, and used by cells to synthesis tissue proteins. The amino acids are first used in synthesizing functional body proteins (hormones, enzymes etc.) when the dietary energy intake is sufficient. They are then used next for tissue repair and synthesis. Amino acids in excess are then broken down to supply metabolic energy or are converted to fat and stored (Barrows and Hardy, 2001).

Protein requirements of *O. niloticus*

Protein is the basic body building nutrient of every growing animal, and muscles constitute anatomically the major component of the fish body. Protein is also used for energy when dietary fat or carbohydrate intake is inadequate to meet metabolic energy demands. According to Barrows and Hardy (2001), tilapia are more efficient at using

protein for metabolic energy than terrestrial animals because they are highly efficient in eliminating nitrogenous wastes through the gill tissues directly into the water and using the de-aminated amino acids for metabolic energy.

Protein is the most expensive ingredient of a fish feed. In general, the optimum level of any dietary nutrient refers to the level which results in maximum growth and this is usually expressed as a proportion (%) of the diet. Fish requires higher levels of protein (32-35 %) for better growth compared to other animals (Jauncey, 1998). Fineman-Kalio and Camacho (1987) investigated the effects of varying crude protein (20, 25 and 30 %) levels in supplementary feeds for *O. niloticus* grown in brackish water and concluded that the 30 % crude protein gave the best growth performance. It has been reported by Cho *et al*. (1985); National Research Council (1981, 1983) that the optimal protein level for *O. niloticus)* ranges from 30 to 35 % when both sexes are raised together. The level of dietary protein to produce maximum growth of fish depends upon the energy content of the diet, physiological state of the animal i.e. age, reproductive state, and environmental factors such as temperature and salinity, amino acid profile and level of food intake. In tilapia, one of the most important factors affecting protein requirements is age. The level of protein requirements of tilapia decreases with increasing age. Protein level requirements vary by size and species. The nutritional value of protein depends on the relative amount of the amino acids present. Although over 200 amino acids occur in nature, only about 20 are common and categorized as nonessential (dispensable) amino acids and essential (indispensable) amino acids. The 10 essential amino acids that must be supplied in the diet are: methionine, arginine, threonine, tryptophan, histidine, isoleucine, lysine, leucine, valine and phenylalanine

(Barrows and Hardy, 2001). Of these, lysine and methionine are often the first limiting amino acids. Fish feeds prepared with plant protein e.g. soybean meal typically are low in methionine; therefore, extra methionine must be added to soybean-meal based diets in order to promote optimal growth and good health. It is important to know and match the protein requirements and the amino acid requirements of each fish species reared (Craig and Helfrich, 2002). Fish which have been fed feeds lacking even a single dietary essential amino acid soon become inactive and lose both appetite and weight. When the missing essential amino acid is replaced in the diet, appetite is restored and growth resumes (Barrows and Hardy, 2001).

Carbohydrate requirements of *O. niloticus*

Carbohydrates are a major source of energy to man, animals and many omnivorous fish, such as catfish and tilapia. Tilapias possess a specialized digestive system capable of digesting carbohydrates (Beveridge and Baird, 2000). All the necessary enzymes for the digestion and utilization of carbohydrates have been found in fish, yet the role of dietary carbohydrates and the contribution of glucose to the total energy requirement of many fish species is not clear (Barrows and Hardy, 2001). Carbohydrate is the most abundant and the cheapest (low cost) form of dietary energy in terms of cost per kJ. The carbohydrate content of feedstuffs can be divided into digestible carbohydrate and indigestible fibre. Jauncey (1998) reported that the digestible portion of carbohydrates is mainly starches with an average digestibility of 60 % , giving a digestible energy (DE) of 10.5 kJg^{-1}. The indigestible portion is made up of complex polysaccharides which, in case of plant material, are principally cellulose. Fish

do not produce endogenous enzymes capable of hydrolyzing fibre, and therefore, are unlikely to utilize it as energy source to any significant extent. High levels of dietary fibre have been shown to reduce growth in some finfish species (Leary and Lovell, 1975). For tilapia, dietary levels above 5 % reduce food utilization and digestibility and levels above 10 % reduce protein utilization (Anderson *et al*. 1984). In low protein diets high fibre levels reduce food intake (Wang *et al*., 1985a). Dioundick and Stom (1990) reported that *O. mossambicus* exhibited high growth performance with feeds containing 2.5-5 % dietary fibre. Shiau (1997) provides a comprehensive review of carbohydrate and fiber utilization in tilapia. Approximately 8 % dietary fiber is generally recommended for many fish species, including tilapia.

After absorption, carbohydrates are either burned for energy, stored temporarily as glycogen, used to synthesize several non-essential amino acids, or converted to fat. If sufficient fat and carbohydrates are not available in the feed, protein will be used to supply the energy at the expense of tissue growth and repair. The use of dietary carbohydrate for energy to save protein for other purposes is known as the protein-sparing-effect of carbohydrate (Barrows and Hardy, 2001). According to National Research Council (NRC) (1993), carbohydrates may supply up to 20 % of the available energy in the ration. This will spare protein since less protein will be used for energy. Cowey and Sargent (1979) observed that increasing the energy level (fat or carbohydrate) of a diet at constant dietary protein always resulted in improved protein utilization.

Apart from providing energy, carbohydrate has the physical function of texturing manufactured feeds by acting as binder in the formulation of pellets (Jauncey, 1998).

For several species of fish such as channel catfish and rainbow trout, up to 25 % level of digestible carbohydrates in the diet can be an effective source of fat (Cowey and Sargent, 1979). There is some uncertainty about the amount of carbohydrates needed in formulated feed for tilapia. *O. niloticus* at temperature of 24 ºC-25 ºC requires a daily supply of 180-200 KJ digestible energy/kg (Wang *et al.*, 1985). Adult fish can tolerate as much as 40 % carbohydrates in their diets without ill effects. According to Anderson *et al*., (1984) and Teshima *et al*., (1985) tilapia feeds should contain up to 40 % digestible carbohydrate. Carbohydrates usually represent less than 25 % of the diet required for fish less than one gram of weight and are increased to 30 % for fish bigger than one gram. Carbohydrates are often supplied by the least expensive ingredients in the diet. Corn, wheat, rice and a number of agricultural byproducts are typical carbohydrate sources. The ratio of energy supplied by lipids and carbohydrates to the proteins available in the diet is often a critical measure (Jauncey, 1998).

Lipid requirements of *O. niloticus*

Lipids are a group of compounds many of which function as important source of metabolic energy. They may be sub-divided into glycerol based compounds (fats, oils, glucolipids, galactolipids, lecithins and cephalins) and non-glycerol based compounds (waxes, cerebrosides, steroids, terpenes and sphingomyelins) (Jauncey, 1998). The glycerol based fats and oils are of much interest in terms of general nutrition. Lipids are essential components of animal cell membrane and are carriers of fat soluble vitamins, precursors of prostaglandins and steroids.

Fatty acids are composed of carbon atom chains with a methyl (CH_3) group at one end and a carboxyl (COOH) group at the other end. Fatty acids of interest in fish nutrition contain 12-24 carbon chains. If the first double bond between carbon atoms occurs at the carbon number 3, counting from the methyl end, the fatty acid is called an omega-3 fatty acid.

E.g. $CH_3CH_2CH{=}CHCH_2CH{=}CHCH_2CH{=}CHCH_2CH_2CH_2CH_2CH_2CH_2CH_2COOH$

Alpha Linolenic acid (omega-3)

Similarly, if the first double bond is found at carbon number 6, counting from the methyl end, the fatty acid is called an omega-6 fatty acid (Jauncey, 1998; Barrows and Hardy, 2001).

E.g. $CH_3CH_2CH_2CH_2CH_2CH{=}CHCH_2CH{=}CHCH_2CH_2CH_2CH_2CH_2CH_2CH_2COOH$

Linoleic acid (omega-6)

Fatty acids may be saturated (no double bonds in the carbon chain), mono-unsaturated (one double bond) or polyunsaturated (more than one double bond). Fatty acids of the n-3 series are more unsaturated than those of the n-6 series. All fatty acids with more than one double bond are polyunsaturated fatty acids (PUFA) whereas those with four or more double bonds are usually identified as highly unsaturated fatty acids (HUFA) (Jauncey, 1998).

Just as there are certain essential amino acids necessary for growth, so there are Essential Fatty Acids (EFA) that cannot be synthesized by fish and must be supplied pre-formed in the diet. Fish are able to add double bonds to fatty acids at some positions but not at carbons 3 (Barrows and Hardy, 2001). According to Tacon *et al*., (1987), most animals are incapable of synthesizing fatty acids with double bonds in the n-6 (omega-6

fatty acid) or n-3 (omega-3 fatty acid) positions. These must therefore, be added to the fish feed during preparation.

O. niloticus has demonstrated a requirement for essential fatty acid (EFA) of the n-6 series (Takeuchi *et al*., 1983; Teshima *et al*., 1982). Santiago and Reyes (1993) demonstrated that n-6 fatty acids enhance spawning success and fry production, while n-3 fatty acids increase weight gain but reduce reproductive performance in *O. niloticus*. This means that for the commercial fish farmer who is interested in weight gain of the fish, an n-3 fatty acid source should be added to the formulated feed. Likewise, the hatchery operator should add an n-6 fatty acid source to the feed formulated for the brood fish. Stickney and Wurts (1986) reported that levels in excess of 1 % omega-6 fatty acid in the diets reduce growth of *Oreochromis aureus* but that was not the same with higher levels of omega-3 fatty acids. Kanazawa *et al*., (1980) reported that *Tilapia zilli* showed an EFA requirement of 1 % n-6 fatty acid in the diet.

Viola *et al*. (1988) reported that at least 2 % lipid supplement was necessary in animal protein-free formulated feeds for tilapia. Dietary lipids function as energy source, supply essential fatty acid and serve as transporters for fat-soluble vitamins (Craig and Helfrich, 2002). Lipids are the most concentrated energy source of the food groups, containing 2.25 times more energy per unit weight than either protein or carbohydrates (Barrows and Hardy, 2001). In addition to supply of energy, lipids serve other functions such as facilitating intestinal absorption of fat-soluble vitamins and as components of cellular membranes and nerve sheaths. They provide the raw material for the synthesis of some hormones and are essential for gonadal development.

According to Werner (1989), besides the stunted growth resulting from inadequate feed utilization, lack of fats in diets gives rise to fin erosion, especially, of the tail fin, swollen light coloured fatty livers and acute local myocarditis. Winfree and Stickney (1981) first reported on the lipid requirement of tilapia, *O. aureus* using different levels of lipid from 2 to 8.6 %. Since tilapia do not appear to effectively utilize high levels of dietary lipid, recommendation for tilapia rations is based on little data. Between 6 and 10 % would appear optimal to maximize growth (Winfree and Stickney, 1981).

Vitamins requirement of *O. niloticus*

Vitamins are organic compounds that are required in small quantities in foodstuffs for normal growth and healthy life (White *et al.,* 1964). They are needed mostly for normal growth, maintenance, and reproduction. Most vitamins are catalytic in nature and function as part of metabolic enzyme systems found in all cells. Vitamins can be classified as fat-soluble vitamins and water soluble vitamins. The fat-soluble vitamins found in lipid fraction of foods are vitamins A, D, E and K. The water-soluble vitamins include the vitamin B complex (thiamine, B_1; riboflavin, B_2; biotin; folic acid; pyridoxine, B_6; cyanocobalamine, B_{12}; niacin; pantothenic acid) and the macrovitamins (vitamin C (ascorbic acid), inositol and cholin) which mainly function as components of phospholipids (Jauncey, 1998; Barrows and Hardy, 2001). Most ingredients used in preparing fish feeds contain some vitamins. For instance, fishmeal and plant oils contain high levels of vitamins A, D and E.

The vitamin requirements of finfish have been reviewed in detail by Halver (1979) and Tacon (1987, 1991). When fishes are confined under artificial conditions and fed with supplementary feeds for fast growth, nutritional deficiencies occur (Lovell, 1979). The absence of a particular vitamin leads to serious metabolic disorders such as avitaminosis. According to Pillay (1990), there is no need to add premix vitamins when preparing feed for fishes cultured under semi-intensive system because the fishes will derive their vitamins and minerals from the natural foods that they consume. However, vitamins and minerals are critical to proper nutrition in tilapia and considerable research has been conducted to determine these requirements (Jauncey and Ross 1982; Roem *et al*., 1990; El-Sayed and Teshima 1991; Watanabe *et al*., 1997). Commercial premixes are available which allow feed producers to purchase a whole group of micronutrients rather than attempting to determine how much is available from the productivity of the system and the other ingredients. The following summary on the roles of some specific vitamins on *O. niloticus* is based on reviews by (Poston, 1986; Tacon, 1987; Conklin, 1989; Halver, 1989; Akiyama and Dominy, 1990 and Chaung, 1990).

Vitamin B_1 (thiamine) is essential in the metabolism of carbohydrates as the co-enzyme co-carboxylase which is required for the oxidative decarboxylation of pyruvic acid and α-ketogutaric acid, as well as the activator of the enzyme transketolase. Natural sources of vitamin B_1 include brewer's yeast, wheat mill, rice bran, groundnut mill, dried fish, soybean meal and rice. Lack of thiamine in the feed could cause anorexia, poor feed efficiency and growth, light coloration and nervous disorder (Lim and Leamaster, 1991).

Vitamin B_2 (Riboflavin) plays an essential role in energy metabolism in the form of flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD), which are the coenzymes associated with the energy yielding breakdown of pyruvic acid, fatty acids and amino acids. Vitamin B_2 can be found in dried torula yeast, chicken egg white, dried fish, skimmed milk and alfalfa meal. *O. aureus* fingerlings fed vitamin B_2 free diet exhibited fin erosion, lethargy, loss of colour, short body dwarfism and cataract (Solliman and Wilson, 1992).

Vitamin B_6 (Pyridoxine) is involved in protein metabolism as the coenzyme pyridoxal phosphate which is required for the non-oxidation of amino acids including transamination, deamination, decarboxylation and sulphahydration. Pyridoxal phosphate is required for the metabolic breakdown of tryptophan to nicotinic acid and the synthesis of heamoglobin, acetyl co-A and mRNA and for the release of glycogen from the muscle and liver. Channel catfish when fed with vitamin B_6 free diet exhibited erratic swimming, blue-green coloration of the dorsal surface and anorexia (Andrews and Murai, 1979).

Natural sources of Pantothenic acid include dried brewer's yeast, groundnut meal, whole hen's egg, wheat bran and dried cane molasses. Pantothenic acid plays an essential role in protein, lipid and carbohydrate metabolism as a component of acetyl co-A, which is necessary for acetylation reactions and subsequent oxidation and release of energy from the major food nutrients. It is also involved in the synthesis of fatty acids, cholesterol, steroid hormone, phospholipid, heamoglobin and so on. *O. aureus* deficient in pantothenic acid exhibited poor growth, sluggishness, high mortality, haemorrhage and anaemia (Roem *et al*., 1991; Soliman and Wilson, 1992).

Vitamin C (Ascorbic acid) plays an essential role in maintaining the integrity of collagenous connective tissue, blood vessels, bone tissue and wound tissue through hydroxylation of tryptophan, lysine and phenylalanine. Natural sources of vitamin C include citrus fruits, vegetables and to lesser extent fish, fresh insect and liver. Jauncey *et al*., (1985), Soliman (1986) and Soliman *et al*., (1986, 1987 and 1994) concluded that tilapias cannot synthesize vitamin C and must be added to the diet during feed preparation. The effects of ascorbic acid deficiency on *Oreochromis niloticus* include poor growth, anorexia, surface haemorrhage, tail erosion and spinal deformity.

Vitamin E (tocopherol) plays an essential role as a fat-soluble anti-oxidant within fish bodies, where it protects reactive compounds (e.g. polyunsaturated fatty acids (PUFA), vitamins A and C) from oxidative damage by acting as a free radical acceptor. Natural sources of vitamin E include barley grain, rice bran, maize grain, soybean meal and wheat middling. The effects of vitamin E deficiency on *O. niloticus* include lack of appetite, reduced growth, poor feed efficiency, skin and fin haemorrhage and muscle degeneration (Satoh *et al*., 1987).

Mineral requirements of *O. niloticus*

There are about twenty (20) minerals considered to be essential for animal life. Thirteen (13) of these are required in the diets of most terrestrial animals and only nine (9) have been demonstrated to be essential in the diets of fish (Davis and Gatlin, 1991). Minerals are classified as macro or micro (trace) depending on the amount required in the diet. The macro-minerals include calcium, phosphorus, sulphur, sodium, chlorine, potassium and magnesium. These are required in large quantities (g/kg) in the diet of the

organism. The micro-minerals are iron, copper, iodine, manganese, cobalt, zinc, molybdenum, selenium and fluorine. These minerals are required in traces (mg/kg) in the diet of organisms.

Minerals are essential components of hard skeletal structures such as bones and teeth. They also play a key role in osmoregulation. Minerals are essential for nerve impulse transmission and muscle contraction. They play vital role in acid-base equilibrium and thus regulate the pH of both blood and other body fluids. Minerals also serve as essential components of many enzymes, vitamins, hormones and respiratory pigments as well as being co-factor in metabolism, catalyst and enzyme activators (Tacon, 1987; Barrows and Hardy, 2001).

A study carried out by Flik *et al*., (1985) indicated that *O. mossambicus* can absorb calcium from the pond water and therefore, concluded that dietary calcium supplementation may not be necessary for any practical tilapia farming. However, Robertson *et al*., (1987) reported that *O. aureus* requires 0.7 % calcium for better growth. Rich dietary sources of calcium include bone meal, poultry manure, fishmeal, dried skimmed milk and poultry by-products.

Phosphorus can be absorbed through the skin, gills and fins. However, the concentration of phosphorus in most culture waters is low and should be added to the diet during feed preparation. Phosphorus is an essential component of hard skeletal materials (bone and teeth) as well as cartilage. Phosphorus plays a key role in energy and cell metabolism and inorganic phosphates serve as buffers regulating blood fluid pH (Jauncey, 1998). Research on phosphorus had received more attention than calcium because of its dietary significance. *O. niloticus* requires dietary phosphorus of between

0.46-1.0 % depending on dietary nutrients and fish size (Watanabe *et al*., 1980; Viola *et al*., 1986; Robinson *et al*., 1987; Haylor *et al*., 1988). Dietary sources of phosphorus include meat meal, fishmeal, shrimp meal, wheat bran, rice bran, dried poultry manure, sunflower seed meal and brewer's yeast.

Magnesium is an essential component of bone and cartilage and is the activator of a large range of enzymes including mutases, kinases, cholinesterase, enolase, arginase, deoxyribonuclease and glutaminase. Magnesium plays an important role in carbohydrate, protein and lipid metabolism. Magnesium is readily absorbed from the culture water through the skin, gills and fins as well as from the gut (Var der Velden *et al*., 1991a). Dabrowska *et al*., (1986 a, b); Var der Velden *et al*., (1989); Reigh *et al*., (1991); Var der Velden *et al*., (1991 b) reported that tilapia requires 0.5-0.77 % of magnesium in their diet for better growth performance.

Chlorine, potassium and sodium occur in body fluids and soft tissues. They play vital roles in osmoregulation and balancing pH. There are no data on these elements in tilapia nutrition. However, (Tacon, 1987; Davis and Gatlin, 1991) suggested that, in most species, dietary sources are dispensable and requirement can be met from the culture water.

Zinc plays a role in the metabolism of protein, lipid and carbohydrate as an enzyme cofactor. Zinc is readily absorbed from the gut or through the integuments. Water borne zinc is toxic to tilapia (Hilmy *et al*., 1987) whereas the dietary zinc is not (Tacon, 1987). McClain and Gatlin (1988) reported a zinc requirement of 20 mg/Kg in *Oreochromis aureus*. Eid and Ghoneim (1994) suggested zinc requirement of 30 mg/Kg in *Oreochromis niloticus*.

Manganese functions as an enzyme activator for enzymes which mediate phosphate group transfer especially in the citric acid cycle. It is essential for bone formation, erythrocyte regeneration, carbohydrate metabolism and the reproductive cycle. Ishac and Dollar (1967) found that *Oreochromis mossambicus* require manganese in both the diet and the culture water to meet a daily requirement of 1.7 mg/Kg. Natural dietary sources of manganese include rice bran, palm kernel meal, wheat bran, copra meal, brewer's grain and shrimp meal.

There are no reports on sulphur, iron, copper, cobalt, iodine, selenium and chromium requirements in tilapia. However, there are reports that suggest the requirement levels in other fishes like the channel catfish, Chinook salmon and trout (Woodall and LaRoche, 1964; Tacon and Beveridge, 1982; Gatlin and Wilson, 1984 and 1986).

In general aquatic animals are able to absorb minerals from both the diet and the culture water. Al-Amoudi (1987) reported that adding 10 % sodium chloride to the diets of various *Oreochromis* species prior to their transfer into sea water enhanced the survival rates of the fish after the transfer. Despite the intrinsic levels of minerals in the feed ingredients it is important to add supplemental minerals in the form of mineral premix to the diets. This will guard against mineral deficiency as a result of reduced bioavailability or antagonism. For instance, high dietary calcium levels have been shown to cause phosphorus, zinc, iron and manganese deficiency in fish (McClain and Gatlin, 1988; Robinson *et al*., 1987).

Feed formulation for *O. niloticus*

Feed formulation is a process in which feed ingredients, vitamins and mineral premix are blended together to obtain a diet that satisfies the nutritional requirements of a particular species. Various kinds of natural feedstuffs of plant and animal origins are normally used together, since no single feed ingredient can provide all required nutrients in correct proportions. Feed ingredients differ in chemical composition and nutrient content (Pillay, 1990; Jauncey, 1998). Feed formulation is meant to provide the species under culture with a well balanced diet that meets its nutritional requirements at different stages of life, so as to yield optimum production at minimum cost (Pillay, 1990).

To formulate feed, the main information needed on the ingredients is the levels of crude protein, energy, specific amino acids, crude fiber and ash. There are no fixed formulae for formulating feed; it may vary according to the availability of ingredients, their composition and cost (Pillay, 1990; Jauncey, 1998). Tacon *et al*., (1987) recommended that the cost per kilogram of feed to be formulated should not exceed 20-25 % of the 'farm gate' price per kilogram for the cultured species. In other words, the market value of the species being considered for culture must justify the cost of the formulated feed to be used. The methods used in balancing the crude protein content include Trial and Error, Pearson Square, Algebraic and Computer Based Least Cost Formulation methods.

Species selection for culture

There is a growing consensus that tilapias (*Oreochromis* sp.) can become one of the world's most important cultured fishes (FAO, 1980). Tilapias are one of the most important fish species for freshwater aquaculture (Siddiqui and Al-Harbi, 1995) and mariculture (Hopkins *et al*., 1989; Watanabe *et al*., 1990). Culturing of tilapia has become more popular around the world because it is easy to culture them in a variety of aquaculture systems, and is a preferable food fish species for most communities. Furthermore, tilapia is known to have performed well in freshwater, brackish water and seawater environments (Chervinski, 1982; Philippart and Ruwet, 1982; Beveridge and McAndrew, 2000).

The Nile tilapia, *Oreochromis niloticus* (L), is the most important tilapia used in African aquaculture, in both freshwater and brackish water culture (FAO, 1997), because of their hardiness, fast growth and attainment of large size as adults. Costa-Pierce (2003) reported that *O. niloticus* is a widely used aquaculture species. It tolerates poor water qualities, and can use a wide variety of natural as well as artificial feed. The attributes which make tilapias, especially, *O. niloticus* so suitable for fish farming are their general hardiness, great tolerance of adverse environmental conditions, ease of breeding, rapid growth rate, ability to efficiently convert organic and domestic wastes into high quality protein, and good taste (Stickney *et al*., 1979; Balarin and Haller, 1982; Pullin and Lowe-McConnell, 1982). These attributes, along with relative low input costs, have made *O. niloticus* the most widely cultured freshwater fish in tropical and sub-tropical countries (Popma and Masser, 1999). In Ghana, the Ministry of Fisheries had also adopted and promoted *O. niloticus* as the recommended tilapia species for fish

farming in the country (Personal communication, 1998). Consumers like tilapia's firm flesh and mild flavour, so its markets have expanded rapidly in Ghana during the past 5 years (personal observation). According to Rakocy and McGinty (1989) the growth performance of *Oreochromis niloticus* is better than any of the *Oreochromis* species. The ranking in descending order could be described as *O. niloticus* > *O. aureus* > *O. rendalli* > *O. mossambicus* > *O. hornorum*. In Malawi, polyculture of indigenous tilapias, *Tilapia rendalli* and *Oreochromis shiranus,* is the common practice but their final fish yields are low (Satia, 1989; Noble and Costa-Pierce, 1992). Among all these species, *Oreochromis niloticus* has for many decades been responsible for the significant increase in global tilapia production from fresh water aquaculture.

Male tilapias naturally grow faster than the females (Hanson *et al*., 1983; Toguyeni *et al*., 1997) making them the better choice for commercial tilapia farming. Fryer and Isles (1972) confirmed this fact in a number of species and attributed this characteristic to genetic causes. However, it can also be associated with the spawning of the females. The females continue to spawn at frequent intervals, even if the eggs are not fertilized. Thus energy is diverted from growth to egg production (Hepher and Pruginin 1981). Females use considerable energy in egg production and some do not eat when they are incubating eggs. Sexually active tilapia channels more energy into reproduction rather than somatic growth (Mair and Little, 1991; Macintosh and Little, 1995). Male monosex culture permits the use of longer culture periods, higher stocking rates and fingerlings of any age. High stocking densities reduce individual growth rates, but yields per unit area are greater. Expected survival for all-male culture is 90 percent or greater (Rakocy and McGinty, 1989). Poor performance of mixed-sex *Oreochromis niloticus* in

semi-intensive systems has been a major constraint to the commercial development of the species (Okorie, 1975; Pillay, 1979; Hepher and Pruginin, 1982; Teichert-Coddington et al., 1997). Use of all-male fingerlings has been identified as the answer to the problem and has been widely promoted and adopted (Green *et al*., 1997). Oral administration of androgens to sexually undifferentiated fry has become the standard commercially adopted technique to produce mono-sex male tilapias (Popma and Lovshin, 1996). In 1998, the Department of Fisheries of the Ministry of Food and Agriculture adopted the oral administration of 17-α methyltestoterone to sexually undifferentiated *O. niloticus* fry as the standard means of producing all-male tilapia in Ghana (personal communication).

Hepher and Pruginin (1982) observed that early breeding of stocked fish could lead to over population, which may exceed the critical standing crop in fertilized ponds, leading to harvests of stunted fish of low value. Even a small percentage of females in the stocked population can reduce the proportion of fish reaching a marketable size of 300 g (Lovshin *et al*., 1990).

Growth

Growth is energetically defined as the change in energy stored as somatic and reproductive tissues (Moyle *et al*., 1988). Werner (1989) also said that growth takes place when the quantity of food ingested exceeds that required for the maintenance of the body. Growth of fish is described in four phases. These are the lag phase, accelerated or log phase, stationary phase and finally the decline phase. Nutritionist and fish farmers are interested in the accelerated phase thus the shorter the period for the fish to reach the

accelerated phase the better. According to Barrows and Hardy (2001) maximum growth of fish within the least time and with minimum input is a function of profit.

Ricker (1979) indicated that, although readily observed and easily measured, growth is one of the most complex activities of the organism. It represents an outcome of a general metabolic system involving internal and external (biotic and abiotic) factors. Many workers have tried to estimate growth rate in nature with a set of methods mainly based on age (size) frequency distribution and marks on scales and bones. Knowledge of quantitative aspects such as length frequency distribution, weight-length relationship and condition factor of fish is an important tool in the study of fish biology. The relationship between weight and length of fish in a given population can be analyzed by measuring weight and length of the same fish throughout their life or of a sample of fish taken at a particular time (Wootton, 1998). Weight-length relationship has been commonly used for two different purposes. Firstly, to describe the mathematical model between weight and length so as to derive one from the other (Wootton, 1990). Secondly, weight-length relationship is used to compute the departure from the expected weight for length of the individual fish or a group of fish as indications of fatness or degree of wellbeing of fish, this relationship is called “Condition factor” (Wootton, 1990). This parameter helps to assess the improvements in an environment for an existing fish. The significance of the study of weight-length in fish is to assess the growth of fish in different environments or conditions (Mirza *et al*., 1988). In fish, the condition factor (K) reflects variations and information on the physiological state of the fish in relation to its welfare. From a nutritional point of view, there is the accumulation of fat and gonadal development (Le Cren, 1951). From a reproductive point of view, the highest K values are reached in

some species (Angelescu *et al.*, 1958). K also gives information when comparing two populations living in different locations; determining the period of gonadal maturation; or even following up on the degree of feeding activity of a species to verify whether it is making good use of its feeding source (Weatherley, 1972).

Factors influencing the growth of *O. niloticus*

Oreochromis niloticus are more tolerant than most commonly farmed fish to high temperature, low dissolved oxygen, high ammonia, high salinity and low pH (Popma and Masser, 1999). High rates of survival of *O. niloticus* in different loads of manure application to ponds were attributed to optimal water quality conditions (Miller, 1975; Parker and Davis, 1981; Ayinla *et al*., 1994).

Dissolved Oxygen (DO) concentration

Aquatic life requires dissolved oxygen (DO). Fish need DO for aerobic generation of energy for body maintenance, locomotion, feeding and biosynthesis (Haung and Chiu, 1997). A minimum DO level of 3.0 ppm was recommended for cage culture of tilapia in freshwater (Coche, 1982). In fish ponds, dissolved oxygen fluctuates greatly due to photosynthetic oxygen production by algae during the day and the continuous consumption of oxygen due to respiration. DO typically reach a maximum during late afternoon and minimum around sunrise. Cloudy weather, plankton die-off, and heavy stocking result in low levels of dissolved oxygen, which can stress or kill fish. Some of the signs exhibited by *O. niloticus* when there is low dissolved oxygen concentration in the pond include sluggishness and poor eating, gasping for air at the

water surface, crowd near water inflow pipe, slow growth and outbreak of diseases (Ingthamjitr, 2003). Tilapia can survive routine dawn dissolved oxygen (DO) concentrations of less than 0.3 mg l^{-1}, considerably below the tolerance limits for most other cultured fish. An excellent aquacultural attribute of tilapia is their tolerance to low dissolved oxygen (DO) concentrations (Teichert-Coddington and Green, 1993). Coche (1982) reported that caged *Oreochromis niloticus* survived several days of 0.7 mg l^{-1} DO level. Chervinski (1982) reported that *O. niloticus* survived a short term exposure to 0.1 mg l^{-1} dissolved oxygen. Survival at 0 mg l^{-1} DO for up to 6 hours was reported for *O. niloticus* in Honduras (Teichert-Coddington and Green, 1993). Tilapia survives short-term anoxia by rising to the water surface to gulp oxygen-rich water, a common response to hypoxia in tropical freshwater fish (Kramer and McClure, 1982). Tilapia also conserves energy by reducing activity in response to hypoxia (Peer and Kutty, 1981). However, extended periods of hypoxia may reduce growth in *O. niloticus* (Chervinski, 1982). At concentrations below 2 mg l^{-1} (Parker and Davis, 1981), fish cease to feed, reduce locomotion and use the available oxygen to support other metabolic systems rather than growth, while fish mortality sets in at DO less than 1 mg l^{-1} level (Ayinla *et al*., 1994). Chakroff (1976) recommended that for best growth performance in *O. niloticus* the DO concentration should be above 5 mg l^{-1}.

Temperature

Water temperature is the single most important factor affecting fish growth. This is because fish are coldblooded and their body temperatures fluctuate with the environmental water temperatures (Barrows and Hardy, 2001). According to Parker and

Davis (1981), in the tropics fish grow best at temperatures between 25 °C and 32 °C, and for reproduction, it is 22-36 °C. The tolerable temperature range for *O. niloticus* is from 12-42 °C. However, growth is retarded in *O. niloticus* at temperatures above 32 °C (Huet, 1994). Yasshour (1958) found out that *O. niloticus* can thrive in ponds at 8 °C for 3-4 hours a day. Bishai (1965) quoted a range of 17.2 to 19.6 °C as the lowest temperature that can support growth in *O. niloticus*. The preferred water temperature for best growth performance in *O. niloticus* is from 27-31 °C (Popma and Lovshin, 1996).

pH

The pH is one of the most common environmental tests that are usually conducted on fish ponds. This measures the hydrogen ions concentration in the water body. Chakroff (1976) recommends pH level of 5-9 in fish ponds to ensure best growth performance in *O. niloticus*. Acidic water destroys gill tissues, causes inflammation and increases mucus secretion in the gills (Schofield, 1976). At pH of below 4, pond water becomes acidic and fish die as a result. There is practically no reproduction in fish when the pond water pH is 4-5. pH values of 5-6.5 slow down fish growth due to poor feeding. Fish usually thrive well and grow fast at pH values of between 6.5 to 9.0. Above pH 11, fish die due to the high alkalinity of the pond water (Schofield, 1976; Ingthamjitr, 2003).

Food Supply

As stated before, food supplies the energy for growth and other body processes. Fish normally use about 70 % of dietary energy for maintenance of their biological systems and activity, leaving about 30 % available for growth (Barrows and Hardy,

2001). Adequate and quality feed should be supplied for the cultured fish to ensure good growth performance.

Stocking rate

The growth performance of tilapia in a fish pond is affected by the stocking density. Beyond the carrying capacity of the water body, growth will be adversely affected even if other factors such as food and others are available. Stocking depends on duration of production, natural productivity of the water and the size of the fish to be produced (Huet, 1994). High stocking density increases yield per unit area but reduces individual growth rates. Reduced stocking density on the other hand increases individual fish growth but decreases total yield per hectare (Balarin and Hatton, 1979). Hepher and Prugnin (1982) recommended that stocking density of an extensive culture system should be about 3,000 to 5,000 fingerlings per hectare whereas 5,000 to 20,000 fingerlings per hectare should be used for a semi-intensive culture system. Bigger fishes need to be stocked at lower densities compared to smaller fishes. For example, *O. niloticus* of 100 g should have a stocking rate of 5,000 fingerlings per hectare while that of 50 g should be stocked at 8,000 fingerlings per hectare.

Turbidity

The presence of suspended solids in the water contributes to the turbidity of the water. Generally, these suspended solids include sediment particles, organic matter like detritus, faecal materials, and phytoplankton (Stickney, 1979). Turbidity can either be harmful or beneficial in fish culture. If water turbidity is due to the presence of

planktonic organisms, it is beneficial since it enhances the growth of tilapia. This is because the planktonic organisms serve as natural food for the tilapia. On the other hand if the turbidity is due to suspended silts or other solids, it could suffocate the fish and eventually result in death. In this case, the suspended particles could cover the gill filaments of the fish thereby preventing effective gaseous exchange in the gills, hence the suffocation to death.

Energy requirement of *O. niloticus*

In physics energy is defined as the capacity to do work. Work can be mechanical (muscular activity), chemical (tissue repair and synthesis, maintenance of biological salt balance), or heat to maintain body temperature. *O. niloticus* require energy for growth, activity, reproduction and osmotic balance; all of which constitute cost of living (Barrows and hardy, 2001). Other factors that affect energy requirement of fish include water temperature, size, age, metabolic rate, composition of the diet and environmental stresses.

Food energy is expressed as calories or joules. A calorie is the amount of heat required to raise a gram of water by 1°C; a kcal (or Cal) is one thousand calories. The total energy value of a feed is the amount that is liberated when the material is completely combusted. Total energy (in nutrition called gross energy) is measured by burning a sample of known weight in a bomb calorimeter and measuring the amount of heat that results. Digestible energy of feed is the amount that can be digested and absorbed in the gastrointestinal tract. Digestible energy is calculated by measuring the gross energy of a sample and subtracting the energy content of the feaces. Thus, the

difference between gross energy and feacal energy is the digestible energy, the portion that was absorbed by the fish. In most fish feeds, digestible energy is between 75-85 % of gross energy (Barrows and Hardy, 2001).

One reason projected for high dietary protein requirements of *O. niloticus* compared to poultry, is that fish preferentially catabolize protein as a source of energy, rather than depositing it as a tissue (Jauncey, 1998). It must, therefore, be a goal in fish nutrition to maximize the use of protein for growth (anabolism) by supplying adequate amounts of alternative dietary energy sources. The total energy content of protein is 23.6 $kJ.g^{-1}$, that of carbohydrate is 17.2 kJg^{-1} and that of lipid is 39.5 kJg^{-1} (Jobling, 1983); therefore, the use of adequate lipid in the diet in the compounded feed could spare protein for growth of *O. niloticus*. El-Sayed and Garling (1988) examined carbohydrate to lipid ratios in *T. zilli* feeds and concluded that, as long as EFA requirement were met, these energy sources can be substituted for one another, based on their physiological fuel values, at a ratio of 2.25:1 (carbohydrate to lipid). Teshima *et al*., (1985) recommended 30-40 % protein, 12-15 % lipid and 30-40 % digestible carbohydrate for *O. niloticus*. Meyer-Burgdorff *et al*., (1989) studied energy metabolism in *O. niloticus* and concluded that increasing the feeding rate, and thus energy intake, resulted in a decline in the availability of gross energy. They recommended that tilapia should not be fed more than 400 $kJME.kg^{-1}.d^{-1}$.

Statement of Problem

Cost of feed is the single largest expenditure in semi-intensive and intensive fish culture operations (Shang, 1981). This is because of extensive reliance on marine animal

protein sources such as fish, shrimp and squid meal to meet the high dietary protein requirements of fish. These feedstuffs have high palatability and nutritional value but are expensive and not always readily available (Lim and Dominay, 1990). Formulated feeds containing fish meal are expensive and often not available to small-scale fish farmers in developing countries (Martinez-Palacios *et al*., 1988) including Ghana.

A problem facing fish culturists around the world is that of finding economical sources of fish feed ingredients at a time when demand and prices for many of the more commonly used products have risen. The problem is more serious in developing nations where the traditional market value of cultured fish (e.g. tilapia) is low, thus limiting the use of relatively expensive feed ingredient like fishmeal in production. Few of these countries can afford the luxury of using animal proteins in feeds and in some countries the cost of cereal grains and legumes is prohibitive (Bayne *et al*., 1976). In Malawi, the most frequently used fishpond input is maize bran, which is usually not available in adequate quantities during the rainy season because it is also used for human consumption during that same period (Kadongola, 1990).

Djunaidah (1993) reported that some of the raw materials for shrimp feed imported into Indonesia included fishmeal, squid meal, wheat gluten, peanut extract, groundnut extract, corn gluten meal, fish or squid oil, premix vitamin or mineral etc. Popma *et al.* (1983) also reported that the feed formulation used in their tilapia project contained 11 % fishmeal, 42 % soybean meal, 30 % wheat middlings, 7 % corn, molasses, minerals and vitamins. According to Barrows and Hardy (2001) organs of slaughtered animals were among the first ingredients used to supplement or replace natural feeds for fishes. Hatchery operators began feeding dry meals (e.g. wheat by-

products, dried skimmed milk, brewer's yeast, or cottonseed meal) combined with meat products to provide greater quantities of finished feed. Use of resources available on-farm (e.g. agricultural by-products) and terrestrial vegetation for tilapia culture is an innovative means of developing low-cost aquaculture where feeds are scarce (Pullin, 1986; Edwards, 1987).

In Ghana most fish farmers do not know what to give to their fish because there is no ready-made fish feed on the market. Most fish farmers therefore, do trial-and-error feed formulations. This ranges from a combination of cassava peels, gari (a native food prepared from cassava) and palm fruit chaff mixed together to wheat bran and pito mash mixed together. Some use pawpaw fruit and kontomere (cocoyam leaves) (Personal observation). Such feeds do not help the fish to develop very well thus resulting in low productivity.

Justification for the study

Ghana is endowed with rich and diverse natural fishery resources both marine and inland. These resources supply over 60-70 % of the national daily animal protein intake. Fish provide food security for a vast majority of the nation's rural poor and reduces poverty for nearly 20 % of the population who directly or indirectly benefit from fishing, fish processing and marketing as an economic activity.

The dwindling fish stocks (both marine and inland) coupled with the high population growth rate has exacerbated the problems of sustainable fishery resource use. Fish farming is seen as one of the means to supplement and enhance the natural fishery capacity. Stock enhancement where fingerlings are raised to restock natural water bodies

and promulgation of laws prohibiting the harvesting of juvenile fishes are the other means by which the natural capacity could be supplemented and enhanced.

The success of fish farming like any other animal husbandry depends on quality feed, which is cost effective and could ensure high profit in the industry. Despite 50 years of fish farming, Ghana has never documented any specific feed formulation (compound feed), which is nutritiously balanced, could float on water and is affordable for commercial fish farming in Ghana. There is no fish feed formulation, in any of the handouts prepared for the Ghanaian fish farmers, capable of ensuring financial viability of fish farming in Ghana. Neither is there any fish feed on the market for prospective fish farmers in Ghana. As a result, feed formulation and feeding among fish farmers lack the necessary guidance to ensure profitable fish farming in Ghana.

The steadily growing importance of aquaculture has made it imperative that the practical fish farmers improve the technique necessary for securing the initial and basic requirements for fish culture (Woynarovich and Horvath, 1980).

General Objectives

The objective of this project is, therefore, to develop a fish feed that is nutritionally balanced; dry but easy to swallow or nip at; able to float on water and cost effective in Ghana.

Specific Objectives

The specific objective is to identify feed formulation that will be nutritiously-balanced; could give the lowest Feed Conversion Ratio (FCR), induce the fastest growth

rate, cost effective, affordable and could make the pelleted feed float on water without the use of an extruder.

CHAPTER TWO

MATERIALS AND METHODS

Study Site

The study was carried out at the Aquaculture Demonstration Centre of the Fisheries Directorate at Ashaiman near Tema, north-east of Accra, Ghana (0º00' and 0º05'W; 5º40' and 5º45'N). The Centre is part of the Government of Ghana Irrigation Authority Projects which made provision for three to five percent of the irrigable land to be reserved for fish farming. The centre has five 0.2 ha grow-out earthen fishponds, twelve 50 m^2 concrete ponds, four 2 m^2 fibre glass tanks, four 0.4 m^2 aquarium tanks and fifteen 6-m^3 hapas. The centre also has a feed mill and a pelletizer for feed preparation.

This study was conducted in fifteen 6-m^3 hapas installed in one of the 0.2 ha earthen fishponds at the Centre. The pond was initially drained, cleaned and the hapas installed such that the base of each hapa was about 30 cm from the bottom of the pond (Plate 7). The pond was then filled with fresh water by gravity from a nearby reservoir to a depth of 1.0 - 1.2 m. The inlet pipe was screened with mosquito netting to prevent wild fishes from entering the pond. The experiments were started on 3rd November 2006 and ended 24nd April, 2007.

Feed Formulation

Five feeds were formulated from wheat bran, fishmeal, soybean cake, maize, palm oil, AD premix (vitamins A and D from Chemico Ltd., Tema), broiler premix (minerals and vitamins from Chemico Ltd., Tema) and the amino acids Lysine and Methionine (also from Chemico Ltd, Tema). Three of the feeds were formulated using the Pearson square method (Pillay, 1990) of calculating crude protein levels (Appendix 31); the fourth feed was a commercial one from GAFCO Ltd (Ghana), an animal feed producing company and the fifth experimental feed, which was also used as the control consisted of wheat bran only. Except for the control feed, all other feeds contained approximately 30 percent crude protein (Appler and Jauncey, 1983; Appler, 1985; De Silva and Perera, 1985; Wee and Ng, 1986).

Wheat bran (Feed A) was chosen as control because it is the common ingredient that runs through all the experimental feeds and it is the most popular ingredient (Edwards *et al*., 1994) used by fish farmers in Ghana (Personal observation).

All the feed ingredients were mixed after weighing, and ground into powder in a mill (Plate 8). Two parts of the powdered feed was then mixed with one part of water after which the feed was moulded into 2 mm pellets in a pelletizer (Plate 9) and sun-dried (Plate 10) for 4 hours.

The feeds were designated A, B, C, D and E; and they had the following compositions:

Feed A: Feed A contained only wheat bran and was used as control.

Feed B: Feed B had fishmeal (10 kg), wheat bran (16 kg), maize (0.5 kg), palm oil (1 kg), broiler premix (0.06 g), AD premix (0.06 g), lysine (0.03 g), and methionine (0.03 g).

Feed C: Feed C was made up of soybean cake (10 kg), wheat bran (16 kg), maize (0.5 kg), palm oil (1 kg), broiler premix (0.06 g), AD premix (0.06 g), lysine (0.03 g), and methionine (0.03 g).

Feed D: Feed D was a commercial feed purchased from GAFCO; it contained protein 30 %, fat 8 %, ash 10 %, fibre 7-8 % and moisture 11 %.

Feed E: Feed E contained wheat bran (16 kg), fishmeal (5 kg), soybean cake (5 kg), maize (0.5 kg), palm oil (1 kg), broiler premix (0.06 g), AD premix (0.06 g), lysine (0.03 g), and methionine (0.03 g).

The price per kilogram of each formulated feed was determined according to the cost of the different ingredients.

The total weight of the different feeds used in raising the fish was recorded at the end of the experimental period and costed, and the total fish production in each hapa was also determined and costed. The market price of one kilogram of tilapia during the experimental period was also determined in order to assess the amount of revenue to be accrued from the sale of fish from each hapa.

A sample of each feed was broadcast on the surface of the pond to determine the sinking rate of each feed. This is because tilapias are pelagic feeders and therefore, prefer floating feeds to sinking feeds. The stop watch was paused immediately the feed begins to sink. The time was then recorded as the duration for that particular feed. The

process was repeated three times and the average floating time was calculated for each feed.

Production of All-male Tilapia

From the progeny of brood fish stocked in a 50 m^2 pond at a ratio of 1 male to 3 females the all-male experimental fishes were produced. The fry which were less than 10 days old (and not longer than 11 mm) were selected and fed with 17α-methyltestoterone (17α-MT) feed for 21 days (Macintosh and Little, 1995). The 17α-MT hormone feed was prepared by dissolving 0.06 g of 17α-MT in 200 ml alcohol and added to a mixture of 400 g fishmeal and 600 g wheat bran ground into fine powder. Tilapia fry less than 11 mm have undeveloped genital organs and treating them with sex hormones like 17α-MT can change the females to males. The fry were fed on the 17α-MT feed at 10 % of their body weight divided into 4 portions daily (at 8:00, 10:00, 12:00 and 14:00 hours Greenwich Mean Time (GMT).

A total of 2,000 sex-reserved fry were transferred into another pond and fed a mixture of wheat bran and fishmeal (60 % wheat bran and 40 % fishmeal) until they attained fingerling size of about 40 g to be used for the feed test experiments.

Experimental Set-up

The 6 m^3 hapas were designated A, B, C, D and E according to the type of feed to be administered to the experimental fishes and were arranged in a 0.2 ha earthen fishpond. Thirty fingerlings were stocked in each of the hapas and covered with a net to prevent birds from poaching. The treatments were assigned among the hapas using a

completely random design (Plate 12) with three replicates per feed, taking into account the effects of hapa location on fish performance. That is, for a particular feed, one of the hapas was mounted near the inlet, another in the middle of the pond and the last one near the outlet of the pond.

Feeding Indices

The feeding rate, feed conversion ratio and feed efficiency were considered in feeding the fish. One-way analysis of variance (ANOVA) was used to determine whether there were any significant differences among the means calculated for the above indices at P = 0.05 using the Minitab statistical package (software) and Norman (1997) statistical table.

Feeding Rate

Fish were fed at a rate equal to 3 % and 2 % of their wet body weight per day (National Research Council, 1993) in three portions at 9:00, 12:00 and 16:00 hours GMT during the first 2 months and the last 4 months respectively. Samples (10 fish) from each hapa of the replicates were weighed individually each fortnight to adjust the quantity of feed based on their current body weight.

Feed Conversion Ratio

Feed Conversion Ratio (FCR) is a ratio of total dry feed consumed by fish to total wet weight gained by the fish. The total feed consumed by the fish at the end of the experiment was recorded. It was assumed that the daily quantity of feed administered to

fish was fully consumed. The total weight gained by the fish at the end of the experiment was also recorded. These values were used to calculate the FCRs of the various experimental treatments.

Feed Efficiency

Feed Efficiency is a ratio of the amount of weight gained by fish to the amount of feed consumed by fish over specific period of time (Barrows and Hardy, 2001). The total weight gained by the fish at the end of the experiment was recorded. Similarly, the total amount of feed consumed by the fish at the end of the experiment was also calculated. These values were used to calculate the feed efficiencies for the various experimental fish at the end of the experiment.

Fish Growth Indicators

A subsample of 10 fish were individually weighed to the nearest 0.1 g fortnightly to determine growth activities. Change in body weight was considered as a function of growth. The mean weight and standard length of fish sampled from each hapa were recorded. The sampled fishes were returned to their respective hapas after the measurements. The Absolute Growth Rate, Specific Growth Rate, Growth Efficiency and Condition Factor of the fish were used to monitor fish growth. Analysis of variance (ANOVA) was used to determine whether there were any significant differences in the means calculated for the above growth indicators at $P = 0.05$ using the Minitab statistical package and Norman (1997) statistical table.

Absolute Growth Rate (AGR)

The Absolute Growth Rate is defined as the increment of weight over a known time interval (Hopkins 1992). That is:

$$AGR = \frac{W_2 - W_1}{t_2 - t_1}$$

where AGR is the Absolute Growth Rate, W_2 and W_1 are final and initial weights respectively and t_2 and t_1 are final and initial time in days respectively.

The Absolute Growth Rate was again estimated using a regression analysis (Semi-log analysis). Here the natural logarithms of the calculated mean weight in grams were plotted against number of weeks of culture. Therefore, the antilog of the gradient of the regression equation was recorded as the Absolute Growth Rate of the experimental fish.

Specific Growth Rate (SGR)

Wootton (1998) defined Specific Growth Rate as:

$$SGR = \frac{\ln W_2 - \ln W_1}{(T_2 - T_1)} \times 100$$

where SGR is the Specific Growth Rate, W_2 and W_1 are final and initial weights respectively and T_2 and T_1 are the final and initial time respectively.

Growth Efficiency

Wootton (1998) defined growth efficiency as:

$$GE = \frac{P_s}{C} \times 100$$

where

GE is the gross growth efficiency, P_s is the increase in weight of fish in a defined time interval and C is the weight of food consumed during the time interval.

Condition Factor

The condition factor was used to compare the state of well-being or fatness of fish. Fulton's condition factor (Ricker, 1975; Bagenal, 1978) is given by:

$$K = \frac{W}{L^3} \times 100$$

Where:

K is the condition factor, W is the final weight and L is the final length.

Survival Rate

This is a ratio of the total number of surviving fishes to the total number of fishes stocked from the beginning of the experiment expressed in percentage. That is:

$$SR = \frac{N_2}{N_1} \times 100$$

where

SR is the Survival Rate, N_1 is the total number of stocked fish and N_2 is the total number of fish surviving.

Water quality parameters

The following pond water parameters - pH, Dissolved Oxygen (DO) and surface water temperature - were monitored fortnightly during the study. The pH of the pond was determined using a pH meter (Hanna model). Three readings were taken from

different locations and the mean calculated. The dissolved oxygen (DO) in pond water was measured in milligramme per litre using a digital DO meter (Jenway model, 9071 UK). The meter was calibrated using a zero oxygen solution prior to measuring the DO content of the pond water close to the surface. Three readings were taken from different locations and the mean found. The water temperature was measured with a digital thermometer. A probe attached to the thermometer was immersed directly in the pond water just below the water surface. The reading on the thermometer after the instrument had stabilized was taken as the pond water temperature. Three readings were taken and the average found. It was recorded in degree Celsius, ˚C.

CHAPTER THREE

RESULTS

Growth of *Oreochromis niloticus*

There was a general increase in body weight of all the fish fed with the various feeds during the study (Fig. 1). However, the growth performance varied for different feeds. The control (Feed A) induced the lowest growth performance throughout the study. Feed E on the other hand induced the highest growth performance throughout the study. This was followed by the fish which were fed Feeds B and D. The growth performances of the B and D fishes were almost the same with one overtaking the other at some points and vice versa (Fig. 1). Fish fed Feed C were third in growth performance after E, B and D. Nevertheless, these consistently performed better than those fed the control feed throughout the study.

Feed E induced the highest mean weight of 267.23 ± 2.12 g within 24 weeks whereas the control induced a mean weight of 147.8 ± 3.90 g. Feeds B, C and D produced mean weights of 195.8 ± 7.98 g, 165.97 ± 1.31 g and 196.1 ± 9.10 g respectively (Fig. 1).

The mean weight gained in fish fed Feed E was significantly higher ($P< 0.05$) than for fish fed on Feeds A, B, C and D (Table 1). There was no significant difference

between the mean weights of fish fed Feeds B and D. They were, however, significantly different from those fish fed control and Feed C.

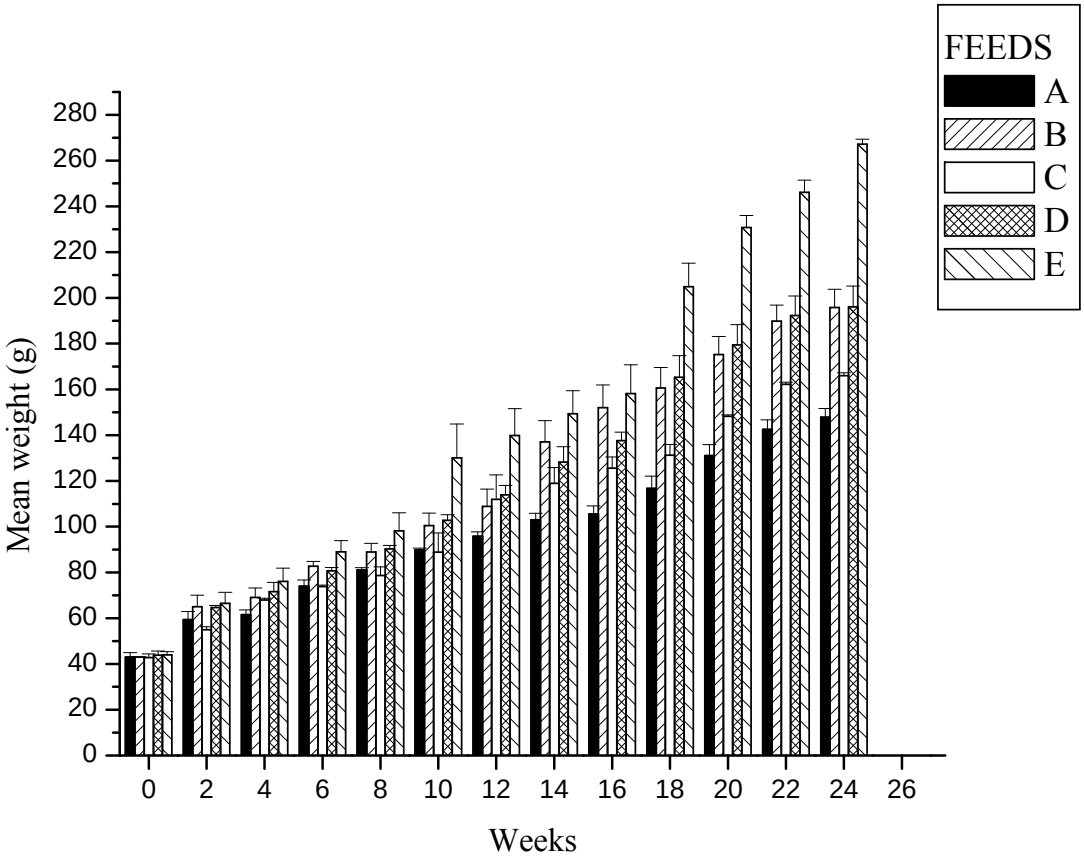

Figure 1: Growth pattern of *O. niloticus* fed Feeds A, B, C, D and E. Vertical bars represent ±1s.e.

Table 1: Final mean weight (g) of *O. niloticus* fed Feeds A, B, C, D and E after 168 days

	Feeds				
Replicates	A	B	C	D	E
1	154.0	211.8	163.4	198.5	263.2
2	148.9	187.9	166.8	180.5	268.1
3	140.6	187.8	167.7	211.9	270.4
Mean ± s.e.[i]	147.8 ± 3.9[c]	195.8 ± 7.98[b]	166.0 ± 1.31[c]	197.0 ± 9.10[b]	267.2± 2.12[a]

i. Values with the same superscript are not significantly different ($P < 0.05$)

Absolute Growth Rate

The highest absolute growth rate, 1.32 ± 0.02 g/day (Fig. 2) was obtained for the fish fed on Feed E, and the lowest, 0.62 ± 0.02 g/day for the control. Rates of 0.90 ± 0.05 g/day, 0.73 ± 0.02 g/day and 0.87 ± 0.33 g/day were obtained for Feeds B, C and D respectively.

Using the regression analysis to determine the absolute growth rate, fish fed Feed E had the highest rate of 1.39 g/day whilst those fed Feed A (control) had the lowest rate of 1.23 g/day. Fish given Feeds B, C and D had 1.33 g/day, 1.29 g/day and 1.36 g/day respectively (Figs. 3-7). Generally, the absolute growth rates obtained using both methods followed the same trend except those of Feeds B and D which interchange

positions. However, estimates from the regression analysis were higher than those obtained using Hopkins (1992) formula.

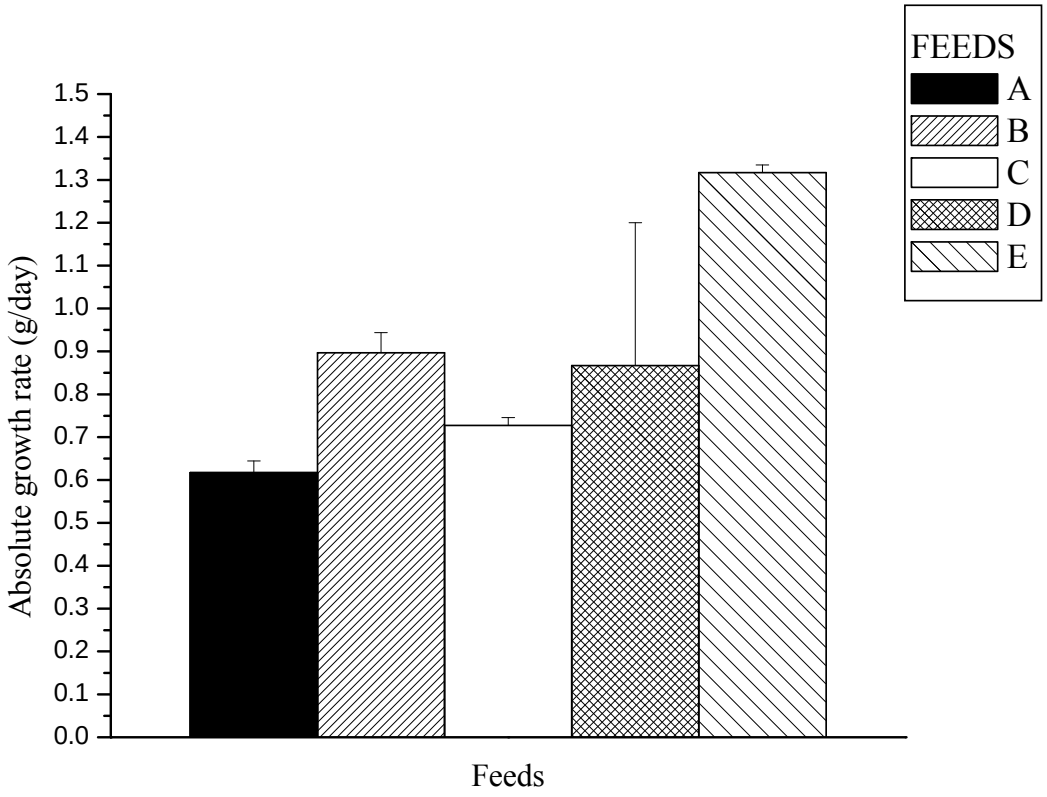

Figure 2: Absolute Growth Rate of *O. niloticus* fed Feeds A, B, C, D and E. Vertical bars represent ±1 s.e.

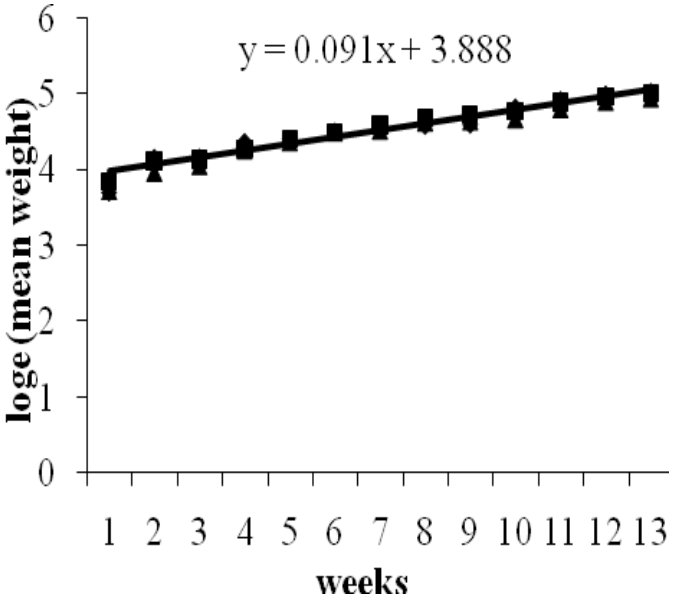

Figure 3: Relationship between mean weight gained by fish fed Feed A and number of weeks fish were cultured

The regression equation was y = 0.091x + 3.8882, where y is the mean weight of fish and x is the time of culture in weeks. The gradient is 0.091; therefore, Antilog of (0.091) equals 1.2340. Therefore, the Absolute Growth Rate obtained with the control, Feed A was 1.23 g/day

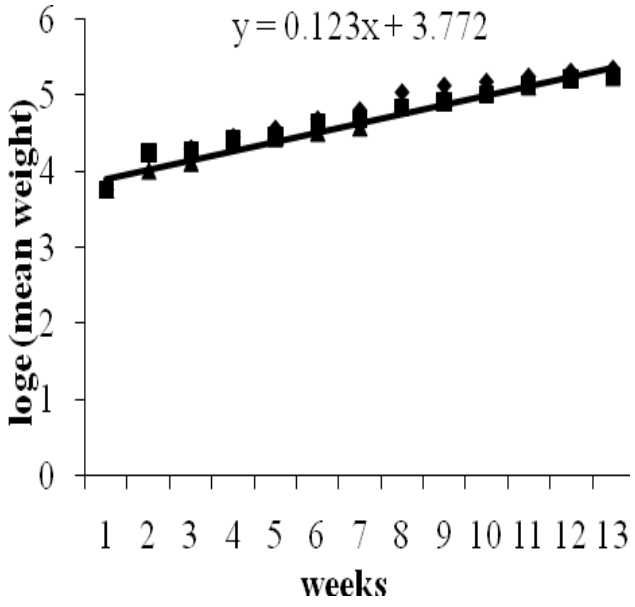

Figure 4: Relationship between mean weights gained by fish fed Feed B and number of weeks fish were cultured

The regression equation was y = 0.123x + 3.7722, where y is the mean weight of fish and x is time of culture in weeks. The gradient is 0.123; therefore, Antilog of (0.123) equals 1.327. Thus, the Absolute Growth Rate obtained with Feed B was 1.33 g/day.

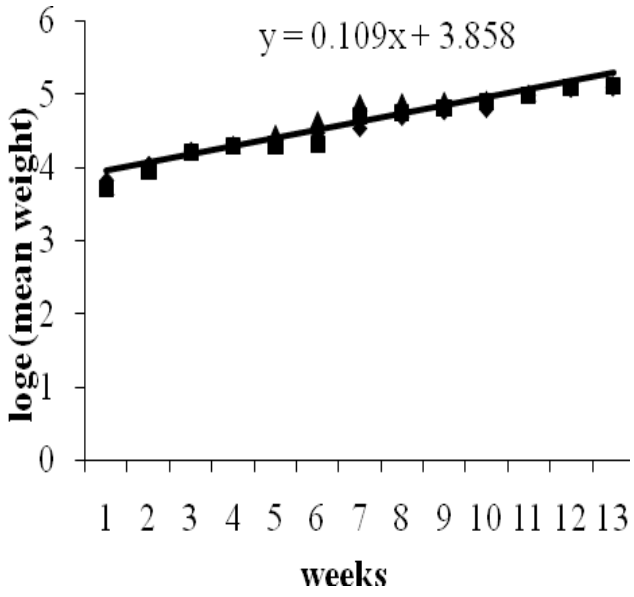

Figure 5: Relationship between mean weights gained by fish fed Feed C and number of weeks fish were cultured

The regression equation was y = 0.109x + 3.858, where y is the mean weight of fish and x is time of culture in weeks. The gradient is 0.109; therefore, Antilog of (0.109) equals 1.2877. Therefore, the Absolute Growth Rate obtained with Feed C was 1.29 g/day.

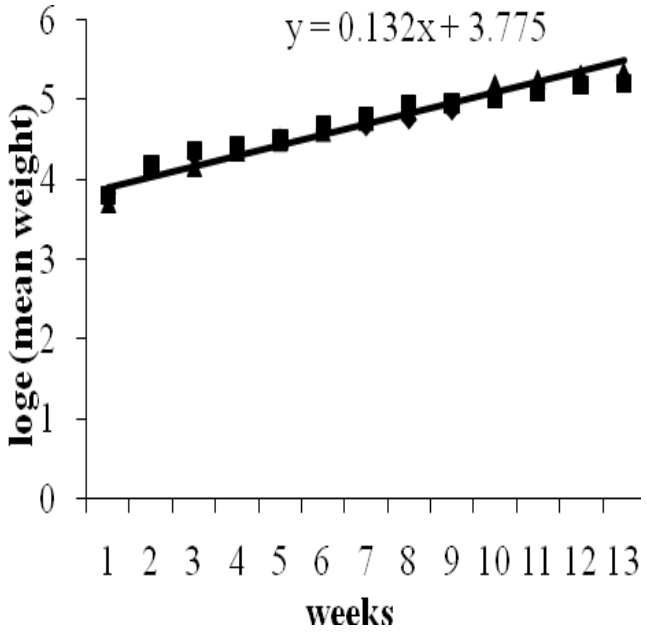

Figure 6: Relationship between mean weights gained by fish fed Feed D and number of weeks fish were cultured

The regression equation was y = 0.132x + 3.7759, where y is the mean weight of fish and x is the time of culture in weeks. The gradient is 0.132; therefore, Antilog of (0.132) equals 1.3561. That is, the Absolute Growth Rate obtained with Feed D was 1.36 g/day

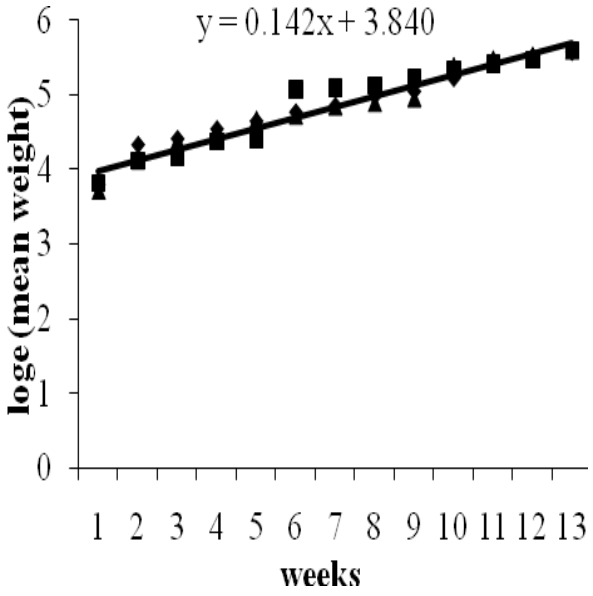

Figure 7: Relationship between mean weight gained by fish fed Feed E and number of weeks fish were cultured

The regression equation was y = 0.142x + 3.8405, where y is the mean weight of fish and x is time of culture in weeks. The gradient is 0.142; therefore, Antilog of (0.142) equals 1.3889. That is, the Absolute Growth Rate obtained with Feed E was 1.39 g/day

The absolute growth rate induced by Feed E was significantly greater ($P< 0.05$) than any of the other feeds (Appendix 4). There was no significant difference between the absolute growth rates of fish fed Feeds B and D. Again there was no significant difference between the absolute growth rates of those fish fed on control and Feed C. However, the absolute growth rate of fish fed Feeds B and D was significantly different from fish fed Feeds A and C.

Specific Growth Rate (SGR)

Fish fed control had the lowest specific growth rate of 0.73 ± 0.05 % per day whilst those given Feed E had the highest specific growth rate of 1.06 ± 0.04 % per day. Feed B induced a specific growth rate of 0.90 ± 0.04 % per day, followed closely by those fish fed Feed D which had a specific growth rate of 0.88 ± 0.09 % per day whereas Feed C induced a specific growth rate of 0.80 ± 0.05 % per day (Fig. 8).

Statistically, the specific growth rate induced by Feed E was significantly ($P < 0.05$) higher than that induced by the remaining feeds. The specific growth rates of fish fed Feeds A, B, C and D were not significantly different from each other (Appendix 5).

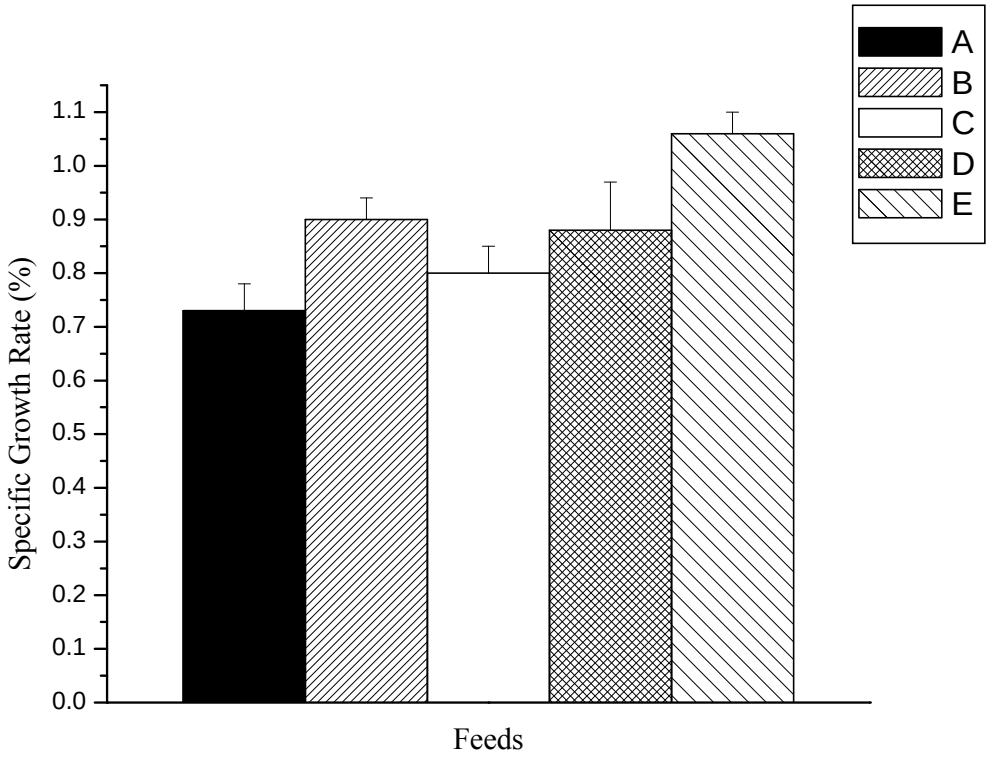

Figure 8: Specific Growth Rate of *O. niloticus* fed Feeds A, B, C, D and E. Vertical bars represent ±1 s.e.

Growth Efficiency

Figure 9 illustrates the mean growth efficiency of groups of fishes given the five feeds. Fishes fed on Feed E exhibited the highest growth efficiency of 1.76 ± 0.02 % whereas those fed the control (Feed A) exhibited the lowest growth efficiency of 1.23 ± 0.01 %. Feeds B, C and D induced growth efficiencies of 1.48 ± 0.01 %, 1.38 ± 0.03 % and 1.44 ± 0.06 % respectively.

Statistically, the growth efficiency of fish given Feed E was significantly ($P < 0.05$) higher than those fed the remaining feeds. But that of fish fed on Feeds B, C and D

was not significantly different (Appendix 6). However, that of fish fed Feeds B and D was significantly different from that fed the control.

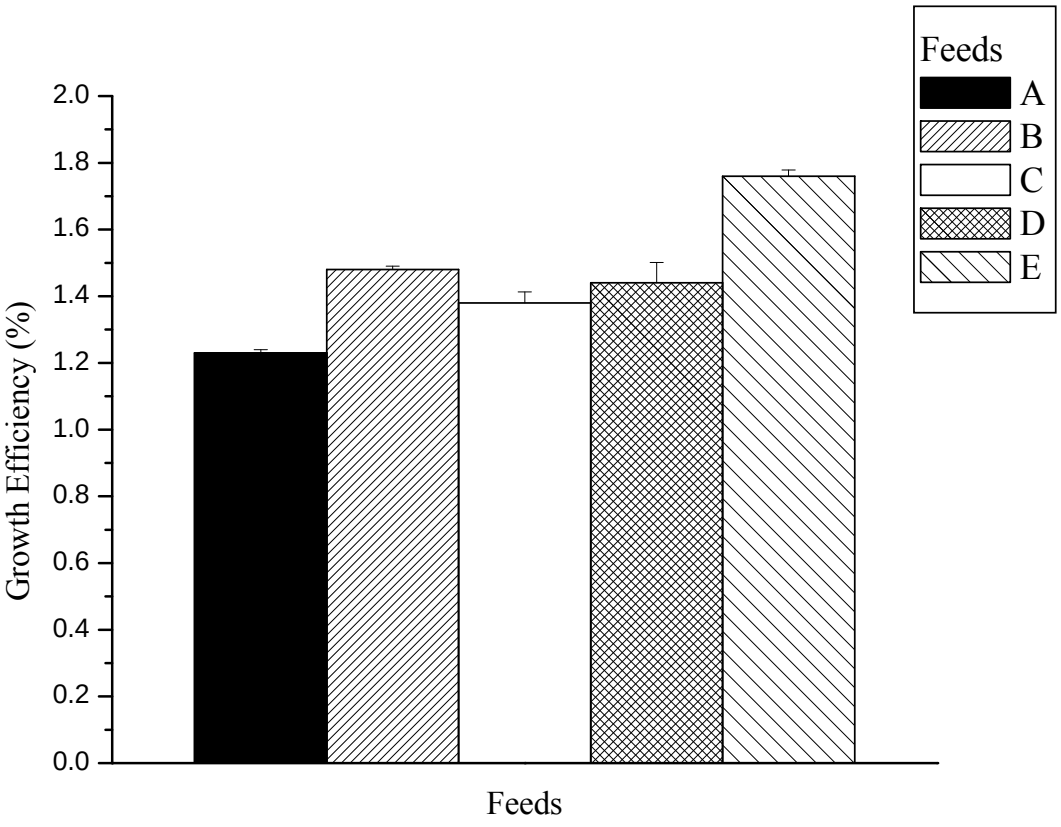

Figure 9: Growth Efficiency of *O. niloticus* fed Feeds A, B, C, D and E. Vertical bars represent ± 1 s.e.

Feed Conversion Ratio (FCR)

Fish fed on control had the highest FCR of 8.37 ± 1.22 after making use of 12.0 kg of feed whereas those fed Feed E exhibited the lowest FCR of 2.47 ± 0.09 (Fig. 10) after consuming a total of 15.2 kg of feed in 168 days. Fish fed on Feed B produced FCR of 4.67 ± 0.05 after consuming a total of 13.3 kg of feed whereas those given Feed D exhibited FCR of 4.83 ± 0.65 making use of 13.7 kg of feed. Those fish fed Feed C on the other hand produced FCR of 5.47 ± 0.65 after consuming 12.0 kg of feed.

Statistically, the Feed Conversion Ratio calculated for fish fed Feed E was significantly ($P < 0.05$) lower than all the remaining feeds (Appendix 7). On the other hand, the FCR obtained for fish fed Feed B was not significantly different from that fed Feed D. However, it was significantly different from those calculated for the control and Feed C.

Feed Efficiency

Those fish fed Feed E had the highest Feed Efficiency of 0.38 ± 0.04 whilst those fed control (Feed A) had the lowest feed efficiency of 0.11 ± 0.02. Fish fed on Feeds C and D induced the same Feed Efficiency of 0.19 ± 0.02 whereas those fed Feed B induced feed efficiency of 0.22 ± 0.03 (Fig. 11).

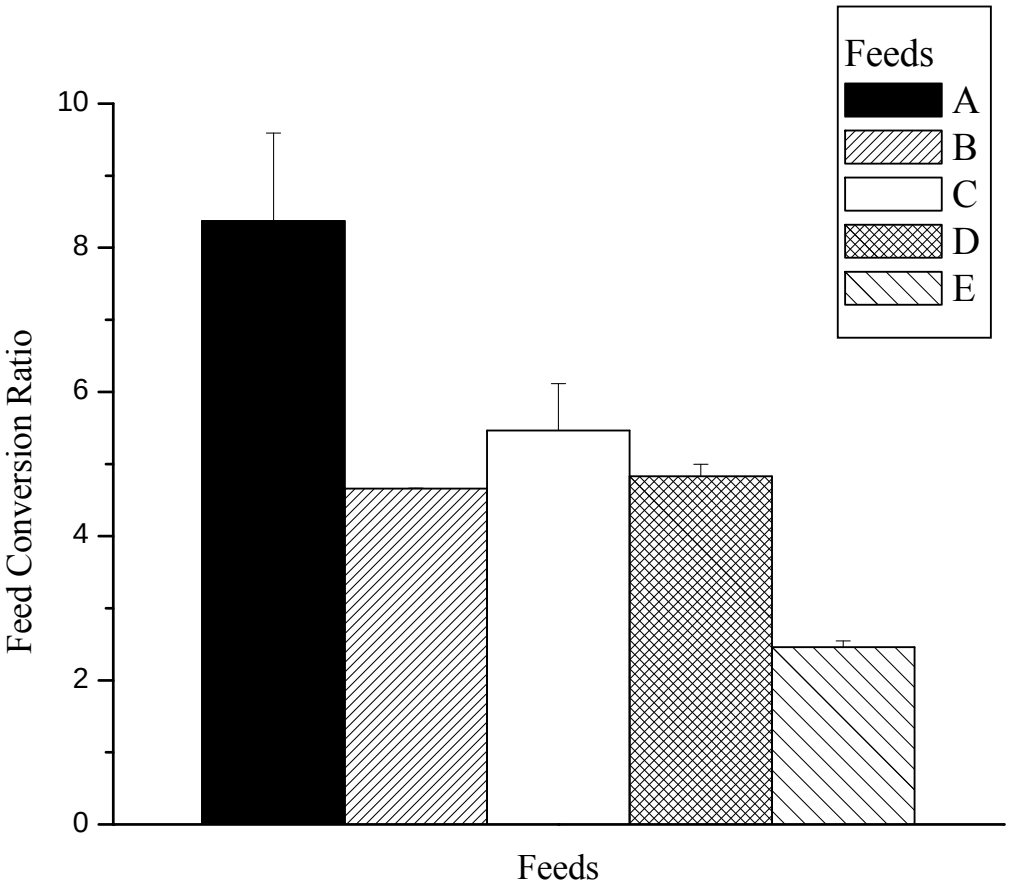

Figure 10: Feed Conversion Ratio of *O. niloticus* fed Feeds A, B, C, D and E. Vertical bars represent ± 1 s.e.

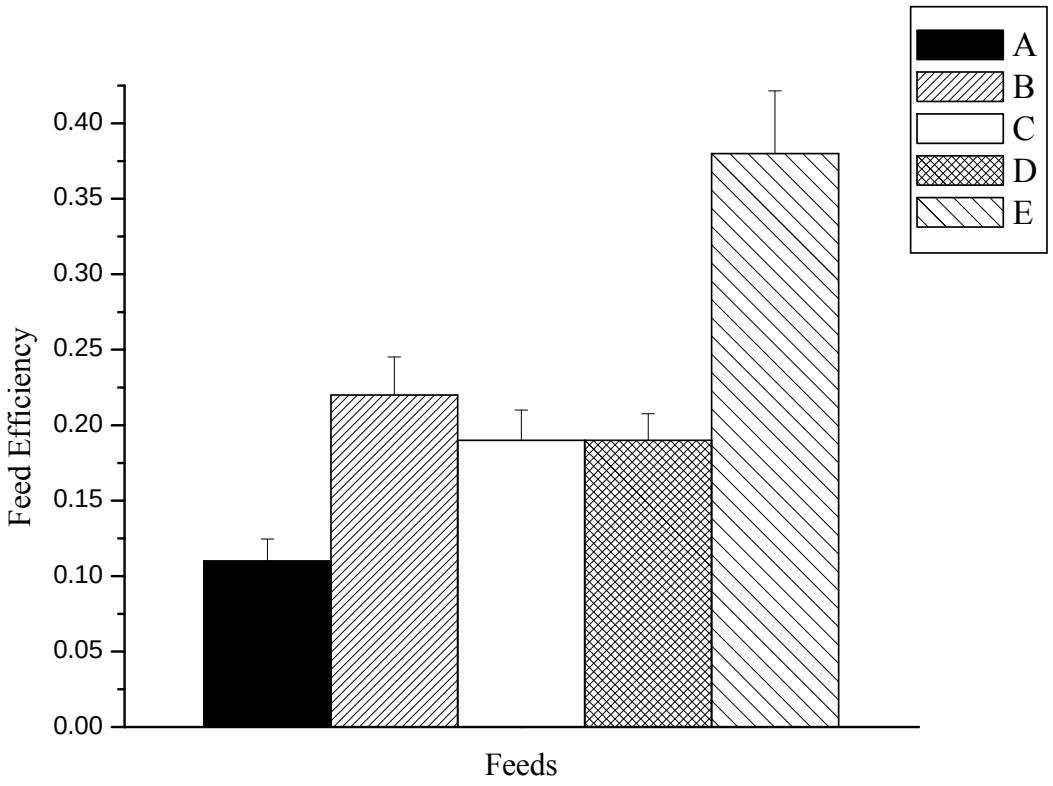

Figure 11: Feed Efficiency of *O. niloticus* fed Feeds A, B, C, D and E. Vertical bars represent ±1 s.e

Statistically, the Feed Efficiency obtained for fish given Feed E was significantly ($P < 0.05$) higher than all the remaining feeds (Appendix 8). The Feed Efficiency figures obtained for fish fed control, Feeds B, C and D were not significantly different.

Buoyancy of Feeds

The control had the best buoyancy of 12.33 ± 1.52 minutes whereas Feed D had the worst buoyancy of 0.03 ± 0.00 minutes (Table 2). Feed C also did not float well on water; it floated for only 0.33 ± 0.01 minutes. Feeds E and B floated on water pretty well for 3.16 ± 0.04 and 3.70 ± 0.17 minutes, respectively.

Table 2: Comparison of buoyancy of Feeds A, B, C, D and E.

Feed	Buoyancy/min (± s.e.)[1]
A	12.33 ± 1.52^{c}
B	3.70 ± 0.17^{a}
C	0.33 ± 0.01^{b}
D	0.03 ± 0.00^{b}
E	3.16 ± 0.04^{a}

1. Values with the same superscript are not significantly different ($P < 0.05$)

Buoyancy of the control was significantly ($P < 0.05$) higher than the rest of the experimental feeds. On the other hand, Feeds B and E were not significantly different from each other. Feeds C and D also exhibited no significant difference between them (Table 2). Feeds B and E were significantly better floaters than feeds C and D.

Condition of Fish

The condition factors for the fish fed on the various experimental feeds were calculated using the final mean weights (Table 1) and the final mean lengths (Appendix 2). The condition factors calculated for fishes fed on control, Feeds B, C, D and E were 3.27 ± 0.08, 3.20 ± 0.12, 3.41 ± 0.04, 2.93 ± 0.37 and 3.16 ± 0.12, respectively (Table 3).

Statistically, the condition factor of fish fed control, Feeds B, C, D and E were not significantly ($P > 0.05$) different.

Table 3: Condition Factor of *O. niloticus* fed Feeds A, B, C, D and E for 168 days

Feed	Condition Factor (± s.e.)[1]
A	3.16 ± 0.12
B	3.20 ± 0.12
C	3.41 ± 0.04
D	2.93 ± 0.37
E	3.27 ± 0.08

1. Values are not significantly different ($P < 0.05$)

Survival Rate

The control induced the lowest survival rate of 43.3 ± 5.07 % whereas Feed E induced the highest survival rate of 93.3 ± 1.93 %. Those fish fed Feeds B, C and D exhibited survival rates of 63.3 ± 6.96 %, 61.1 ± 6.75 % and 62.2 ± 4.47 % respectively (Table 4).

The survival rate of fish fed Feed E was significantly ($P < 0.05$) higher than those fed on control, Feeds B, C and D. Survival rates of those given Feeds B, C and D were not significantly different from each other but were significantly different from those fed on control.

Table 4: Survival rate of *O. niloticus* fed Feeds A, B, C, D and E for 168 days.

Feed	% Survival (± s.e.)[1]
A	43.3 ± 5.07^{c}
B	63.3 ± 6.96^{b}
C	61.1 ± 6.75^{b}
D	62.2 ± 4.47^{b}
E	93.3 ± 1.93^{a}

1. Values with the same superscript are not significantly different ($P < 0.05$)

Plate 1: Mounted hapas in a 2,000 m^2 earthen fishpond

Plate 2: Grinding of feed ingredients

Plate 3: Moulding of experimental feed into pellets

Plate 4: Sun-drying of pelleted feed

Plate 5: Feeding of experimental fish

Plate 6: Random arrangement (Labeling) of experimental hapas

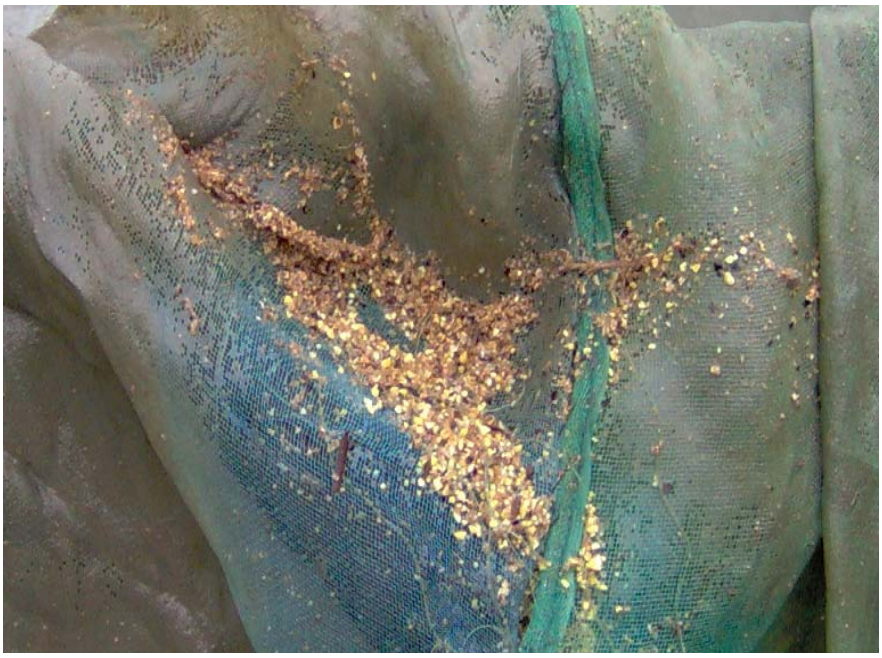

Plate 7: Some uneaten portions of Feed D (mainly maize)

Plate 8: Initial size of *O. niloticus* fingerling (total length 13.6 cm, 44.9 g)

-

Plate 9: Maximum size of *O. niloticus* given Feed A for 168 days (total length 21.3 cm, 142.9 g)

Plate 10: Maximum size of *O. niloticus* fed Feed B for 168 days (total length 23.8 cm, 242.0 g)

Plate 11: Maximum size of *O. niloticus* given Feed C for 168 days (total length 21.5 cm, 169.7 g)

Plate 12: Maximum size of *O. niloticus* fed Feed D for 168 days (total length 23.6 cm, 220.4 g)

Plate 13: Maximum size of *O. niloticus* given Feed E for 168 days (total length 27.3 cm, 389.7 g)

Fish Production

Total fish production was calculated using the final mean weight and total surviving fish. Fish given Feed E had the highest production of 6.26 ± 0.37 kg whereas those fed on control had the lowest fish production of 1.36 ± 0.23 kg. Fish fed Feeds B, C and D had production levels of 2.94 ± 0.83 kg, 2.25 ± 0.35 kg and 2.83 ± 0.18 kg respectively (Fig. 12).

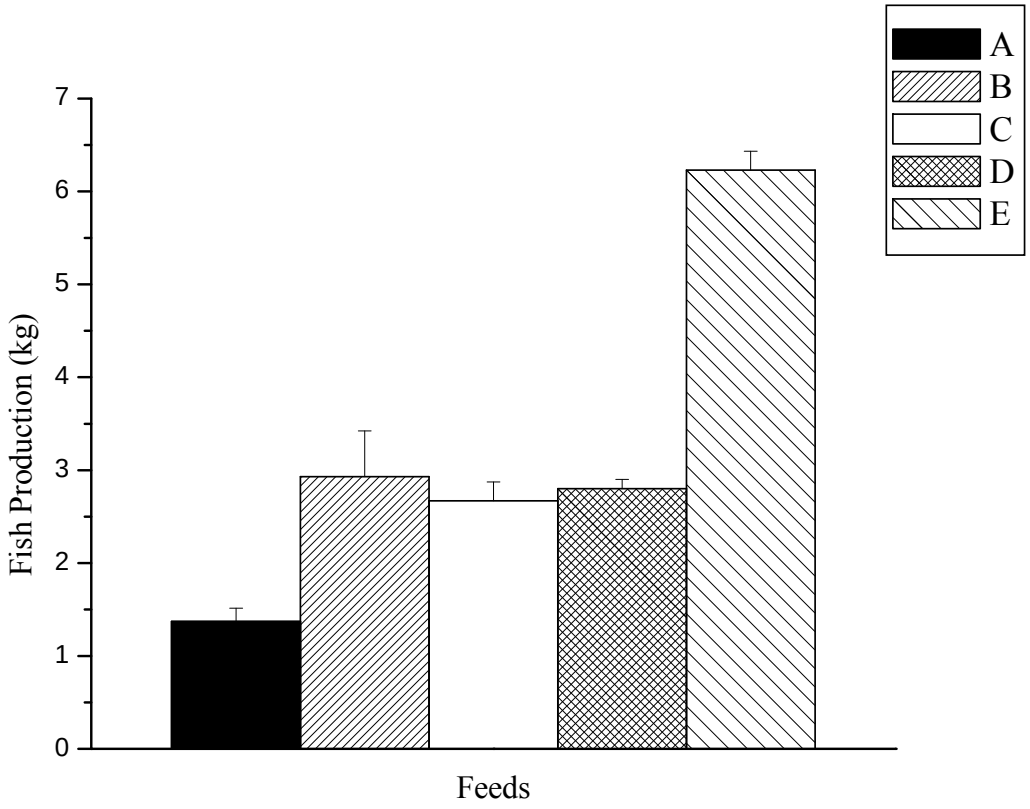

Figure 12: Production of *O. niloticus* using Feeds A, B, C, D and E. Vertical bars represent ± 1s.e.

The production of *O. niloticus* using Feed E was significantly higher ($P < 0.05$) than those fed the control, Feeds B, C and D (Appendix 9). The production of fish fed Feeds B, C and D exhibited no significant differences among themselves but was significantly different from those fed the control.

Cost of Feed Ingredients

Fishmeal was the most expensive per kilogram weight among the four major ingredients used in the formulations. Fishmeal cost GH¢ 0.70 per kilogram whereas soy bean cake, maize and wheat bran cost GH¢ 0.50, GH¢ 0.25 and GH¢ 0.08 respectively (Table 5). Among the feed additives methionine was the most expensive and AD premix was the least expensive. The former was GH¢ 4.5 per kilogram whereas the latter was GH¢ 0.90 per kilogram.

Table 5: Cost per kilogram of feed ingredients

Item	Quantity/kg	Price (GH¢)	Cost per kilo (GH¢)
Wheat bran	25.0	2.00	0.08
Soy bean cake	50.0	25.00	0.50
Fishmeal	25.0	17.50	0.70
Maize	50.0	12.50	0.25
Palm oil	4.5	4.50	1.00
Broiler Premix	2.5	5.80	2.32
Methionine	1.0	4.50	4.50
Lysine	1.0	3.80	3.80
AD premix	1.0	0.90	0.90

Based on the above unit cost of the various ingredients, the cost of producing one kilogram of the control (Feed A) was GH¢ 0.08 whereas that of Feed B, Feed C, Feed D

and Feed E were GH¢ 0.35, GH¢ 0.27, GH¢ 0.51 and GH¢ 0.32 respectively (Appendix 10). Feed D was the most expensive feed as compared to the rest. This was followed by Feed B, E, C and the control in decreasing order.

At the end of the experiment the total fish produced by those fed Feed E was 6.26 kg (Appendix 10). This when sold at GH¢ 3.00 per kilogram (farm gate price for 1 kg tilapia as at the time of conducting this study) accrued GH¢ 18.78. Similarly, fish fed control, Feeds B, C and D accrued GH¢ 4.80, GH¢ 8.82, GH¢ 6.75 and GH¢ 8.49 respectively. The total cost of feed consumed throughout the period to produce the above-mentioned revenues were GH¢ 0.96, GH¢ 4.70, GH¢ 3.20, GH¢ 7.00 and GH¢ 4.00 for Feeds A (control), B, C, D and E respectively. Therefore, profit after deducting the cost of Feeds A, B, C, D, and E will be GH¢ 3.12, GH¢ 4.12, GH¢ 3.55, GH¢ 1.49 and GH¢ 14.78 respectively (Appendix 10).

Water quality parameters

Growth is retarded when temperatures are above the optimal temperature range of 32 ºC (Huet, 1970; Lovell and Li, 1978). The surface temperature of water recorded during the study ranged from 26.03 ± 0.03 ºC to 30.60 ± 0.00 ºC (Appendix 11). The lowest temperature of 26.03 ± 0.03 ºC occurred in December and January, and the highest temperature of 30.6 ± 0.00 ºC occurred in April. The dissolved oxygen (DO) concentration recorded was highest in December (8.13 ± 0.03 mg/L) and January (8.13 ± 0.03 mg/L) whereas the lowest DO concentration occurred in April (7.43 ± 0.03 mg/L). The highest pH of the pond water recorded during the study was in November (8.70 ±

0.06) and April (8.70 ± 0.06) whereas the lowest pH was recorded in December, January and February (7.50 ± 0.00).

CHAPTER FOUR

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Discussion

The current study, on the growth and survival of *Oreochromis niloticus* (L) fed on formulated feeds, was carried out for 168 days in hapas mounted in a 2,000 m^2 earthen fishpond. Five feeds were used to determine their effects on growth performance, feed conversion ratio, fish production, survival rate and profitability in commercial tilapia farming in Ghana.

In formulating the experimental feeds, three scenarios were considered, i.e. use of both fishmeal (animal protein) and soybean cake (plant protein) as sources of protein; fishmeal only as source of protein; soybean cake only as source of protein and wheat bran only as control. As already indicated, wheat bran was used as a control because it is the common ingredient that runs through all the experimental feeds. It is also the cheapest feed ingredient and widely used by livestock, poultry and fish farmers (Edwards *et al*., 1994) in Ghana. Wheat bran was reported to have a crude protein of about 18.8 % and most of the grain vitamins but high in fibre (Gohl, 1981; National Research Council, 1983; New, 1987; Tacon *et al*., 1987).

The availability of the feed ingredients on the local market and their costs were also considered before they were selected for the feed formulation. The major feed ingredients widely used by most Ghanaian livestock and poultry producers are wheat

bran, soybean cake, fishmeal and maize. Thus a poultry or livestock farmer would have no problem with the basic ingredients if he or she decides to include fish farming in his or her activities.

Fishmeal was selected as a source of animal protein for this study because it contains approximately 60-68 % crude protein, 3-5 % crude lipid, 0.9 % crude fibre, 0.8 % carbohydrate and 21-29 % Ash (National Research Council, 1983; Tacon *et al*., 1987; Kamarudin *et al*., 1989). Fishmeal is a rich natural source of minerals especially, calcium and phosphorus, the amino acids lysine and methionine. It also contains the polyunsaturated fatty acids (PUFA), especially the longer chain members of the n-3 series. Fishmeal is highly palatable and digestible in tilapia (Jauncey, 1998).

Soybean meal on the other hand contains a crude protein of 47 % crude protein, crude lipid of 5.3 %, crude fibre of 6.6 % and 6.7 % ash (Gohl, 1981; National Research Council, 1983; Tacon *et al*., 1987; Davies *et al*., 1989; Kamarudin *et al*., 1989). Soybean meal contains relatively high levels of the amino acid lysine but low in cystine and methionine. It is also poor in the vitamin B complex and some minerals. In the current study soybean meal was used as a plant protein source in the diet formulations.

Maize was chosen as one of the feed ingredients for diet formulation in the current study because it serves as a good binder and a source of carbohydrate. Kamarudin *et al*., (1989) reported that maize contains about 76.8 % carbohydrate, 4.6 % crude fibre, 5.6 % crude lipid, 9.1 % crude protein and about 2 % ash.

Based on the report of other authors (Mahnken *et al*., 1980; Davies and Wareham, 1988), methionine, lysine, premix vitamins and other minerals were added to the formulated experimental feeds. These authors observed that methionine deficiency

and Essential Amino Acid (EAA) imbalance could reduce efficiency in growth and feed utilization when diets containing plant proteins are provided. Broiler premix was used in the current study as a source of vitamins and minerals. It contains all the essential minerals and vitamins required for fish growth and development. In addition, another preformed vitamins A and D were also added to the formulated feeds to ensure that the experimental fish are adequately supplied with the requisite vitamins.

Palm oil was included in diet formulations to serve as source of lipid and to aid buoyancy of the pelleted feed. Palm oil is lighter than water and so it floats on water. It was therefore, expected that its addition to the formulated diets will help the compounded feeds to float on water. Palm oil contains up to 20 % crude protein, 6.4 % crude lipid, 49.3 % carbohydrate and up to 5.8 % ash (Gohl, 1981; National Research Council, 1983; Tacon *et al*., 1987; Davies *et al*., 1989; Kamarudin *et al*., 1989). Palm oil has a deep orange-red colour due to the high content of carotenoids. Palm oil is also a rich source of vitamin E, namely tocopherols and tocotrienols (Nesaretnam and Muhammad, 1993). Both β-carotene and vitamin E are well-known nutritional antioxidants. Lim *et al*., (2001) observed that growth and feed efficiency of *C. gariepinus* responded significantly in a positive manner to palm oil additions of up to 8 %, with no further improvement beyond this dietary level. Al-Owafeir and Belal (1996) reported that palm oil could replace soybean oil in feeds for *O. niloticus* without any negative effects on fish growth or body composition. In the current study, 3.6 % of palm oil was added to all the experimental feeds as a source of fatty acid and dietary energy source.

The high percentage of carbohydrate (mainly wheat bran) used in the current study was to aid buoyancy of the pelleted feed. The carbohydrate component of the experimental feeds was about 60 % by weight. This was contrary to a suggestion by Cowey and Sargent (1979) that the maximum digestible carbohydrate for most fin fish species should be around 25 %. Wang *et al*., (1985b) reported that crude starch was well utilized by *Oreochromis niloticus* at levels between 30 and 70 % of the diet. According to Jauncey (1998), carbohydrates are 'non-essential' dietary nutrients for tilapia but should still be included in the feed because they are a cheap source of dietary energy (in terms of cost per KJ); they can, to some extent, 'spare' dietary protein for growth; they improve the pelletability and water stability of feeds.

All male tilapia were used in this study because the male tilapia naturally grows faster than the females (Hanson *et al*., 1983; Toguyeni *et al*., 1997) making them the better choice for commercial tilapia farming. Poor performance of mixed-sex *O. niloticus* in semi-intensive systems has been a major constraint to the commercial development of the species (Okorie, 1975; Pillay, 1979; Hepher and Pruginin, 1982; Teichert-Coddington *et al*., 1998). Hepher and Pruginin (1982) observed that early breeding of stocked fish leads to densities that may exceed the critical standing crop in fertilized ponds, leading to harvest of stunted fish of low value. Even a small percentage of females in a stocked population can reduce the proportion of fish attaining a marketable size of 300 g (Lovshin *et al*., 1990). Use of all-male tilapia fingerlings has been identified as the answer to this problem and has been widely promoted and adopted (Green *et al*., 1997).

From the growth curves it was observed that the growth of *O. niloticus* did not enter the stationary phase, which implies that the fish could not attain their maximum growth (weight) during the period of the experiment. However, the final mean weight of 267.23 ± 2.12 g attained at the end of the experimental period by fish fed Feed E is an acceptable table size fish on the Ghanaian markets (Personal Observation).

The growth pattern of *O. niloticus* in this study was similar to those obtained by other researchers (Olvera-Novoa *et al.,* 1990; Olvera-Novoa *et al.,* 2002). The average daily weight gains were always higher for fish receiving the compounded Feeds (B, C, D and E) than for those feeding on only wheat bran. This means that the compounded feeds were of better quality than the control feed.

The growth rates observed in fish fed Feed E were similar to those obtained by Bayne *et al.* (1976). They had 1.33 g day^{-1}, 1.16 g day^{-1} and 0.72 g day^{-1} for tilapia fed on feed formulated without coffee pulp, tilapia fed on feed formulated with 30 % coffee pulp and tilapia fed on control feed, respectively. The absolute growth rate of 1.32 ± 0.02 g day^{-1} obtained in fish fed on Feed E was almost the same as the one obtained by Dadzie (1982) in his experiment on species combination in tilapia culture. He obtained absolute growth rate of 1.30 g day^{-1} for *O. niloticus* and 0.90 g day^{-1} for *Tilapia zillii*. The growth rate of 1.32 ± 0.02 g day^{-1} by *O. niloticus* was higher than that observed in tilapia cultured in other systems. In hybrid culture, for example, a growth rate of only 0.9 g day^{-1} was achieved by the hybrid of a cross between a female *O. niloticus* and a male *T. hornorum* in two independently conducted trials: the first in Uganda (FAO, 1967), and the second in Brazil (Lovshin *et al*., 1974). In monosex culture, Sanchez (1974) reported a growth rate of only 0.5 g day^{-1} in *T. aurea.* A higher growth rate of

0.96 g day^{-1} was achieved in monosex culture of male *O. niloticus* (Lovshin *et al*., 1974), but this is still low compared with the 1.32 ± 0.02 g day^{-1} recorded in the current study.

When the absolute growth rate was determined using regression analysis, the values obtained were higher than those obtained using the Hopkins (1992) formula. This is perhaps due to the fact that the regression analysis takes into consideration the individual bi-weekly growth rates together in a straight line and their common calculated gradient represents the absolute growth rate of the fish. Hence, the increase in the values of the growth rates calculated with the regression analysis could be due to the steeper alignment of the best points on the line. On the other hand, the Hopkins (1992) method considers only the final mean weight in calculating the absolute growth rate of the fish. The differences between the values obtained with both formulae are statistically significant ($P < 0.05$) when subjected to t-test (Appendix 32). Therefore, regression analysis may not be the best method for estimating the absolute growth rate in *O. niloticus*. This is because the growth of fish is best described with a sigmoid curve indicating four growth phases. These are the lag phase where growth is generally slow, the accelerated phase where growth is very fast, the stationery phase where there is no growth and the decline phase where fish loses weight or dies. The absolute growth rate calculated at any of the phases may be different from each other. It will, therefore, not be appropriate to use a straight line to describe the growth of fish as in the case of regression analysis where the growth rate (gradient) is the same at any point on the line. The stationery phase usually represents the maximum size a fish could attain in its life cycle. Fish farmers are interested in this maximum size and the time that this maximum

size could be attained in a culture cycle. This is because the earlier it is attained the less expenditure on feed and for that matter the better the profit to be accrued. The stationery phase could not be attained by any of the experimental fishes in the current study because of the short duration of the experiment. The t-test gave a Pearson correlation of 88 %, which implies that there, exists a direct or positive relationship between the Hopkins and the regression estimates though the difference is significant.

The specific growth rates (SGR) obtained in this study were lower than those obtained by Mbahinzireki *et al*. (2001) in an experiment where tilapia, *Oreochromis* species was fed cottonseed meal-based diet. This is expected because Mbahinzireki and his colleagues carried out their experiment in a recirculatory system where the environmental conditions are far better than the hapa system. Although the authors failed to specify which *Oreochromis* species (*aureus*, *mossambicus* or *niloticus*) they used, the fact still remains that the SGR they obtained were higher than those obtained in the current study.

The idea behind feed conversion ratio (FCR) is to find out how much feed given actually goes into building fish flesh. Fish fed on Feed E had FCR of 2.46 ± 0.08 and this represents the quantity of feed which when given to the fish will result in a unit gain in body weight. Fish given control, Feeds B, C and D produced FCR of 8.37 ± 1.22, 4.66 ± 0.06, 5.47 ± 0.65 and 4.83 ± 0.17 respectively and these represent the amount of feed needed in each case to build a unit of fish flesh. Therefore, the lower the FCR the better the quality of feed applied. This is because a smaller quantity of feed is needed to build a unit of fish flesh. This also means that less money (in terms of input) is required to produce a unit of fish flesh. These FCR values in the current study are high except Feed

E which is comparable to that reported by Coche (1982); Popma and Lovshin (1996). This should have been around 2.0 which is normal for heavy feeding with high protein content. Miller (1975) suggested that low feed conversion values between 3 and 1.2 were desirable for fish fed agricultural by-products. Therefore, the 2.46 obtained for fish fed Feed E is quite acceptable and economical for commercial tilapia culture.

Feed conversion efficiency depends on dietary content, feed formulation, frequency of feeding and favourable environment (Hepher and Pruginin, 1982). In addition, Coche (1982) established that FCR is affected by water temperature, water exchange rate, dissolved oxygen, daily feed ration and feed distribution. The higher FCR values obtained in some of the feeds could be linked directly to dietary content of the feeds. For instance, the absence of both animal and plant proteins in the control feed; lack of plant protein in Feed B; absence of animal protein in Feed C and similarly Feed D might also lack certain ingredients which could lead to the high FCR values recorded. This suggests the superiority of Feed E (in terms of content) over the rest of the experimental feeds. The high conversion values recorded for some treatments could be due to mortalities or escape of some of the experimental fish from some hapas. Feeding rate was calculated assuming 100 percent survival of the stocked fish. It was observed that fish fed Feed D could not utilize all the quantity of feed (Plate 13) given them because some portions of that particular feed were hard and not palatable for the fish. This uneaten feed could also account for the high FCR recorded for Feed D apart from its poor quality. The maize content in this particular feed was not ground properly, hence could not be eaten by the fish. While it is true that fish cannot grow if essential nutrients are lacking in the feed, it is equally true that feed cannot efficiently produce fish flesh unless it is consumed.

Barrows and Hardy (2001) reported that if a feed is deficient in any one of the 10 essential amino acids, poor growth and increased feed conversion ratio will result, even if the total protein level in the feed is adequate. It is therefore, likely that Feed C (which does not contain animal protein) and Feed D might be lacking certain essential amino acids for which reason they produced high FCR values. According to Richie and Garling (2003), fish sometimes eat more feed than their stomachs can hold. This extra feed eaten passes over the stomach and is considered wasted. This form of feed wastage could lead to an increase in cost of production, lower profits and high feed conversion ratio.

Feed efficiency is the ratio of weight gained by fish and the total feed consumed by the fish over a specific period. When the value of this ratio is high it implies the fish had efficiently converted the feed into fish flesh whereas low value of the ratio indicates poor efficiency of feed conversion into fish flesh. Results from this study indicate that Feed E was most efficiently converted into fish flesh whereas the control feed was poorly converted into fish flesh. It could also be deduced that Feed B was a better formulation than Feed D though the fish fed on the two feeds had almost the same final mean weights. This is because the fish was able to convert Feed B more efficiently into fish flesh than Feed D. However, their means were not significantly ($P > 0.05$) different from each other.

The higher the value of growth efficiency the better the quality of feed consumed. In other words, most of the feed is more efficiently converted into fish flesh if the calculated growth efficiency value is relatively high. In the current study, Feed E induced the highest growth efficiency of 1.76 ± 0.02 % whereas the control feed induced the lowest growth efficiency of 1.23 ± 0.01 % as had been the case for all the growth

parameters. Feed E therefore, is far superior in quality than the rest of the experimental feeds. Hofer *et al.* (1985) observed that roach (a small freshwater fish) fed on meal-worms grew by an average of 89 g in three weeks whilst those fed grass grew by 6.3 g. Roach fed grass used more than twice grass (in terms of weight) than that used by those fed meal-worms, yet the gross growth efficiency of the former was only 8.9 % compared with 46.2 % in the latter. *Barbus liberiensis*, a cyprinid of West Africa, had maximum gross growth efficiency of 25.7 % when fed on shredded beef muscle, but only 5.5 % when fed groundnuts (Payne, 1979). In both examples, fish fed an animal based diet had the advantage of higher growth rate and growth efficiency. The growth efficiencies reported in these examples are far higher than those recorded in this current study because of differences in species of fish used.

The growth performance recorded by the floating experimental feeds in this study were similar to the one obtained by Cremer and Zhang (2000); the mean weight of fish fed floating feeds was better, on average, than fish fed the sinking feeds. They also found out that the floating feeds on average gave superior performance in terms of final body weight, feed conversion and net income. The use of floating feeds was demonstrated to improve revenue relative to sinking pelleted feeds. This could be due to improved digestibility and reduced feed wastage, both of which are beneficial to the environment (Swich, 2001); good digestibility implies less faecal matter will be egested to the environment, and most of the floating feeds will be used by tilapia before they absorb water and sink to the bottom of the pond. These might explain why fish given Feed E exhibited superior performance than any of the experimental feeds. Again Feed B which has better buoyancy than Feed D (sinking feed) also exhibited better FCR and

income than Feed D, though they induced almost the same final mean weight. Tilapias are pelagic feeders and therefore, prefer to pick feeds on the surface of the water. When the feed administered to tilapia could float on water then it is more convenient and easy for it to consume more of the diet and there will be less wastage of feed. Less wastage of feed in the culture system means less money is spent on production cost and likely more revenue will be accrued. Fish feeds are expensive and can amount to 50 % or more of the variable cost of most fish culture operations.

The control feed, Feeds B and E floated whilst Feeds C and D did not. Feed C contained soybean cake and maize both of which are quite heavy and could have accounted for the inability of Feed C to float on water. Similarly, Feed D contained a lot of maize which was not properly ground before moulding into pellets and this could have accounted for its inability to float. Feed E on the other hand contained half the quantity of soybean cake contained in Feed C and could have accounted for the lighter weight of Feed E and its ability to float on water. If the control (raw wheat bran) could float on water and Feed B (mainly fishmeal and wheat bran) could also float on water, it implies that the floating ability of Feed E depended on the presence of the wheat bran and the fishmeal. It also implies that the higher the quantity of wheat bran available in the feed formulation the better its buoyancy and vice versa. It can also be deduced that the higher the quantity of soybean cake in the feed the lower its buoyancy because soybean cake may have added more weight to the formulated feed. Hence, it is essential to balance the soybean cake, fishmeal, maize and wheat bran properly to ensure flotation of the compounded feed without compromising on the crude protein level needed for a particular feed. Palm oil (source of lipid) is also a floating ingredient that can help keep

the feed floating. However, in the current study, the presence of palm oil in Feed C could not make it float on water. This means that to formulate a feed that can float without the use of an extruder, the basic ingredients (wheat bran and fishmeal) must be properly balanced to support and keep the other ingredients afloat. It is therefore, advisable that the fishmeal should not be contaminated with sand during preparation; drying of fishmeal on the bare floor should not be encouraged. This is because sand is heavy and its presence in fishmeal or any other feed ingredient could make it sink faster than it should naturally do. It is again advisable to use clean water (or tap water) in mixing the feed to ensure its floatation. This is because the pond water often contains algae and sand particles which may add undesirable weight to feed and thereby reduce its ability to float significantly. During drying the feed must be allowed to properly dry before they are collected and stored for future use. This is because the half-dried feed will not float well and could grow moulds in no time leading to spoilage. Therefore, during dull weather the drying duration should be extended beyond the 4 hours to make sure the feed is properly dried.

The survival rates obtained in the current study were lower than that obtained by Ridha (2006). *O. niloticus* fed on the control had the lowest survival rate of 43.3 ± 5.07 whereas those fed Feed E had 93.3 ± 1.93 %. Nevertheless, the survival rate obtained for *O. niloticus* fed on Feed E in the current study was within the range (90 percent or greater) expected for all-male culture (Rakocy and McGinty, 1989). Therefore, it can be concluded that good quality feed can ensure better growth and survival of the fish and for that matter could yield good profit in commercial tilapia farming.

In fish, the weight is considered to be a function of length (Weatherley and Gill, 1987). The relationship between weight (W) and length (L) typically takes the formula $W= a L_b$, or in the linear form log W = log a + log L, where a and b are constants estimated by regression analysis.

According to Wooton (1990), if the fish retains the same shape and its specific gravity remains unchanged during its lifetime, it is growing isometrically and the value of exponent "b" would be exactly 3.0. A value significantly larger or smaller than 3.0 indicates allometric growth (Bagenal and Tesch, 1978). A value less than 3.0 shows that the fish becomes lighter (negative allometric) or greater than 3.0 indicates that the fish becomes heavier (positive allometric) for a particular length as it increases in size (Wootton, 1998). Most fishes do not confirm the cube law because they change their shape with growth (Ali *et al*., 2000). The cube law may be held in some cases (Salam and Davies, 1992). The exponent "b" may have value significantly lower or higher than 3.0. The value of "b" may vary with feeding, state of maturity, sex and further more between different populations of a species indicating taxonomic differences in small populations.

Generally, fish with a high value of K (condition factor) are heavy for their length, while fish with a low value are light for their length. In effect, the K value for a given fish measures its deviation from some hypothetical ideal fish of that species growing isometrically (Wootton, 1998). Statistically, the condition factors of fish fed the control, Feeds B, C, D and E were not significantly different. This means that all the experimental fish grew isometrically. The condition factors obtained in this study were similar to those obtained by Huang and Chiu (1997). They had condition factors ranging

from 3.30 to 3.46 and were not significantly different. Fishes go through several developmental stages in their life cycle; for example, fry fingerling, adult, development of gonads, production of eggs and milt, spawning, etc. In each of these stages, the length and weight of each fish are usually highly correlated (Wootton, 1998). A fish can change in weight without changing in length or may change in length without changing in weight. If the weight increases more rapidly than the cube of length, K would increase with increase in length. When the weight increases less than the cube of length, K would tend to decrease with the growth of the fish (Javaid and Akram, 1972).

There may be differences in the length-weight (L-W) relationships due to sex, maturity, season and environmental conditions (e.g. pollution). In a comparative study on L-W relationships of *O. niloticus* and *O. aureus* in polluted and non-polluted parts of Lake Mariat, Egypt, Bakhoum (1994) reported that there were highly significant variations of L-W relationships of both species in polluted and non-polluted parts of the lake. In a similar work, Khallaf *et al*. (2003) reported differences in L-W relationships of *O. niloticus* in a polluted canal compared with those of other authors in different localities and times. These differences were attributed to the effect of eutrophication and pollution on growth and other biological aspects of the fish. The *O. niloticus* in the current study were observed to be in good condition, as the values were higher than those obtained by Olurin and Aderibigbe (2006). In their study on juvenile *O. niloticus* samples from Sanni Luba fish farm, Nigeria they had condition factors of 1.14 and 1.08 for male and female *O. niloticus,* respectively. The comparatively high condition factors recorded in the current study could be due to the age difference (juvenile and adult) in the fishes used.

It is concluded that the *O. niloticus* fed the various experimental feeds were in good condition and healthy and could be used for commercial production. The quality of feed did not affect the condition index in the current study, and this is in agreement with the observation by Olurin and Aderibigbe (2006) that feed availability rather than quality determined the condition of the fish.

The control was the cheapest of all the experimental feeds costing only GH¢ 0.08 per kilogram. However, *O. niloticus* fed the control feed exhibited the lowest growth performance. It is therefore, not advisable to depend on the low cost of wheat bran for commercial tilapia culture.

Locally a kilogram of Feed D cost GH¢ 0.51, making it the most expensive feed. The growth of *O. niloticus* given Feed D was almost the same as those fed Feed B which cost only GH¢ 0.35 per kilogram. It would therefore, be more economical to use Feed B instead of Feed D for *O. niloticus* culture in Ghana.

Feed C on the other hand cost GH¢ 0.27 per kilogram and induced better effect on growth of *O. niloticus* than the control. Economically, however, it is not the kind of formulation that can ensure profitability in commercial tilapia culture. This is because Feed C sinks very fast and for that matter most of it could not be available for the fish but rather go waste. The growth effect of Feed C on *O. niloticus* indicated that it is not advisable to use only plant protein as the source of protein in fish feed formulation (Olvera-Novoa *et al.,* 2002) due to some amino acid deficiencies and, to a lesser extent, the presence of antinutrients in plant protein based feeds. Ofojekwu and Ejike (1984) also reported a much lower weight gain and feed efficiency of *O. niloticus* fed cottonseed (plant protein) cake diet as compared with tilapia fed a fishmeal based diet.

The effect of Feed C on *O. niloticus* in the current study confirmed the report that 100 % replacement of fishmeal with soybean cake led to 27 to 33 % decline in growth performance as compared to a complete fishmeal diet (Wu and Jan, 1977; Davis and Stickney, 1978; Jackson *et al*., 1981). However, the percentage decline in growth performance in the current study was only 15 % and this could be as a result of the addition of methionine to the diets in the current study. According to Shiau *et al*., (1987) for very high levels of soybean meal inclusion in a diet it is imperative to supplement methionine to overcome the principal essential amino acid deficiency. Viola *et al*., (1988) reported that so long as the amino acid profile of soybean meal based diets is well balanced by using amino acid supplements, the growth of tilapia fed soybean meal will be the same as those fed fishmeal based diet. Pantha (1982) found out that about 75 % of fishmeal could be replaced with full fat soybean meal with methionine supplementation without any negative effect on growth. Schmittou *et al*., (1998) estimated the requirement of *O. niloticus* for lysine and methionine to be higher than that published by National Research Council (1993). Shiau (1989) also found out that methionine addition to a low protein (24 %), high soybean diets without fishmeal resulted in an increase in growth of *O. niloticus*. The effect of Feed C on growth of *O. niloticus* in the current study agreed with the suggestion that soybean based diet intended for the culture of *O. niloticus* should be supplemented with methionine.

The cost of producing a kilogram of Feed E was GH¢ 0.32 (Appendix 10) which was the third highest in terms of cost. However, Feed E was the best in terms of growth enhancement as compared to the rest of the feeds. It may therefore, be more economical and beneficial to use Feed E for commercial tilapia culture. The superior performance of

Feed E on *O. niloticus* could be attributed to the presence of both animal (fishmeal) and plant protein (soybean meal) sources in the diet formulation of Feed E. The combination of these protein sources ensure the presence of almost all the dietary amino acids and energy required by *O. niloticus* for better growth and survival. According to Jauncey (1998), animal products have well balanced amino acid profile (including lysine and methionine) and are rich sources of dietary protein, lipid (polyunsaturated fatty acids, especially the n-3 series), minerals (particularly calcium and phosphorus) and vitamins as well as being highly palatable for fish. On the contrary, plant products tend to be deficient in amino acids, especially lysine and methionine as well as some vitamins. Plant derived feed ingredients are however, rich sources of lipid or carbohydrate energy and dietary fibre which aids pelletability of the compound feed. Because of its high quality and palatability, fishmeal has been a major ingredient in all complete artificial feeds for fish; and it could constitute up to 40 % or more of the feedstuffs in a feed (Wee, 1988). But due to the high cost of fishmeal and its availability much research has been conducted on several sources of plant proteins as substitutes for the more expensive fish meal, partially or completely. These included soybean meal by (Brandt 1979; Jackson *et al*., 1982; Quartararo *et al*., 1998), cacao husks by (Pouomogne *et al*., 1997), various cereals by (Al-Ogaily *et al*., 1996) and brewery draff by (Pouomogne *et al*., 1992). As already mentioned the research on plant protein alternatives covered napier grass (Chikafumbwa, 1996), sunflower seed meal (Jackson *et al*., 1982) and cottonseed meal (Robinson *et al*., 1984a, b; El-Sayed 1990) among others.

The current study in formulating Feed E chose soybean meal to replace about 50 % fishmeal in Feed B. The growth performance of *O. niloticus* fed Feed E (animal and

plant proteins combined) was far better than those fed Feed B (mainly animal protein) and Feed C (mainly plant protein).

In aquaculture, the price of fish is determined by the market demand of supply which includes size and production. Two primary goals of fish farming are to maximize production efficiency and to produce fish of more or less uniform size (Noakes and Grant, 1992). Fish production is the total sum of individual weights of all reared fish or a cross-product of the number of surviving fish and their mean weight (Miao, 1992). It is clear, from the results, that Feed E could generate enough profits to take care of other costs (fingerlings, lime, labour, etc) of production. The use of Feed D due to its high cost is likely to incur losses because the profit of GH¢ 1.49 (Appendix 10) is so small that it might not be able to take care of other costs of production. Feed B therefore, is comparatively better than Feed D, though both were almost equal in enhancing growth in *O. niloticus*. Economically, fish fed control feed generated more profit than those given Feed D. However, the final sizes of tilapia play a role in its marketability; for that matter buyers may prefer and pay better prices for tilapia of 197.0 ± 9.1 g (fish given Feed D) to those of 147.8 ± 3.9 g (fish given control). Nevertheless, wheat bran could be used to feed tilapia where there is not enough money to afford compounded feed. Brummett (2000) reports that most fish consumed in rural Africa are less than 200 g and that huge demand among poorer people exists. In Ghana, there exist demands for fried tilapia of even less than 10 g in weight (Personal Observation). Several studies from both Asia (AIT/DOF, 2000; Barman *et al*., 2002) and Africa (Brummett, 2000) suggested that small-size individual fish are acceptable in many rural areas because their

prices are low and many fish farmers prefer to produce them since there is very low risks attached to its production.

The cost/benefit analysis from this study indicates that solely animal protein based feed are more profitable than solely plant protein based feed, contrary to that observed by Olvera-Novoa *et al.* (2002).

Fish are sensitive to water quality and therefore, feeding should be reduced or stopped if water quality falls below certain levels (Richie and Garling, 2003). Shortly after feeding, dissolved oxygen levels decline rapidly. Dissolved oxygen levels should be maintained above 5.0 ppm for best growth. At dissolved oxygen levels between 3.0–5.0 ppm feeding should be reduced, and feeding should be stopped at dissolved oxygen levels below 3.0 ppm. Miao (1992) found that lower pH and DO affects growth and survival of fish. Fish need DO for aerobic generation of energy for body maintenance, locomotion, feeding and biosynthesis. A minimum DO level of 3.0 ppm was recommended for cage culture of tilapia in freshwater (Coche, 1982). The dissolved oxygen concentration recorded in the current study ranged from 7.43 ± 0.03 mg/L to 8.13 ± 0.03 mg/L. This means that DO concentration in the pond during the experimental period was adequate to ensure better growth and survival of the experimental fish.

The surface water temperature recorded in the current study ranged from 26.03 ± 0.03 ºC to 30.60 ± 0.00 ºC. This agrees with the assertion by Parker and Davis (1981) that in the tropics fish grow best at temperature between 25 °C and 32 °C. It was however, a degree Celsius below the minimum recommended by (Popma and Lovshin, 1996). They recommended 27-31 °C for best growth performance in *O. niloticus*.

Considering the good growth performance of *O. niloticus* fed Feed E in the current study, Parker and Davis (1981) claim that the temperature range for best growth performance in *O. niloticus* in the tropics is from 25 – 31 °C could be more acceptable than that of Popma and Lovshin, 1996 though the difference is not statistically different.

The pH values of the pond water recorded during the study was a minimum of 7.50 ± 0.00 and maximum of 8.70 ± 0.06. These are within the recommended pH range for best growth performance in *O. niloticus* (Chakroff, 1976).

Conclusions

Oreochromis niloticus fed Feed E produced superior growth performance, over 93 percent survival rate, better feed conversion ratio and a higher production potential than any of the experimental fish given control, Feeds B, C and D. Feed E again demonstrated good floating ability and was more economical for use in commercial tilapia culture. Feed E is therefore, capable of ensuring high profit when used in commercial *O. niloticus* farming in Ghana.

The current study had demonstrated that diets formulated with different sources of protein (both animal and plant) tend to induce high growth performance in *O. niloticus*. Jauncey (1998) suggested that even different sources or types of fishmeal could be combined in a diet formulation since the amino acid profile and minerals in each source of fishmeal may vary slightly. Some fishmeal may contain more calcium due to the presence of more bones in the raw materials.

The current study also demonstrated that fishmeal-based (animal protein) feed induced better growth performance, and floated better than soybean-based (plant

protein) feed. For this reason, in preparing one source protein diet animal protein should be chosen over plant protein. Even though wheat bran, soybean cake, fishmeal and maize as major ingredients were good for the tilapia, maize might not be palatable to the fish since maize which was not well ground (in Feed D) were left uneaten in the hapa. According to Barrows and Hardy (2001), very little carbohydrate (usually less than 1 % of the wet weight) is found in the bodies of fish. For that matter, carbohydrates are not considered as essential nutrient for fish. It is therefore suggested that maize is excluded in future experimental formulations and should be replaced by wheat bran which is mainly carbohydrate. Again the soybean cake could replace the binding effect of maize in the formulation.

The study also showed that floating fish feeds can be produced without the use of an extruder since the lighter weight of wheat bran when properly balanced with other feed ingredients can make the final pelleted feed float on water.

The findings of this study indicated that the control (Feed A), which was mainly wheat bran, effected some growth in *O. niloticus* and some profits were accrued as well. Wheat bran can therefore, be used in feeding tilapia where funds are not enough to buy compounded feed.

Recommendations

Feed E induced superior growth performance, was converted more efficiently into fish flesh and was economical for use in tilapia culture and should therefore, be adopted for field trials. Feed E should be tried on *O. niloticus* in both earthen fishpond and cage culture systems to assess its growth enhancement potentials.

More research is needed to determine the effects of using maize and maize bran in feeds for *O. niloticus.* Further research is again needed to determine the effect of this formulation (Feed E) on other species like *Heterotis niloticus* and *Clarias gariepinus*, which are also cultured in Ghana. Further studies are needed to determine whether the same effect could be obtained at higher stocking densities like $5/m^2$, $7/m^2$, $10/m^2$ and $15/m^2$.

Food supply (quality and quantity) to tilapia may have a strong influence on its reproductive performances (Brummett, 1995), it is therefore, recommended that Feed E should be tried on mixed sex tilapia to ascertain its effect on reproduction in *O. niloticus.*

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APPENDICES

Appendix 1: Bi-weekly mean weight (g) gained in *O. niloticus* fed Feeds A, B, C, D and E for 24 weeks

Mean Weight (g)	CONTROL (FEED A)			FEED B			FEED C			FEED D			FEED E		
	A_1	**A_2**	**A_3**	**B_1**	**B_2**	**B_3**	**C_1**	**C_2**	**C_3**	**D_1**	**D_2**	**D_3**	**E_1**	**E_2**	**E_3**
Initial Wt- 3/11/06	40.8	46.8	41.4	43.4	42.7	42.8	46.0	40.8	41.6	46.4	44.7	40.4	44.7	45.9	41.3
2 weeks - 17/11/06	64.6	61.0	52.7	70.9	69.2	54.9	57.1	52.4	55.2	66.2	65.0	62.9	76.2	61.3	62.0
4 weeks – 1/12/06	64.8	62.1	57.6	74.5	71.8	61.0	69.4	67.4	67.2	73.2	77.7	63.9	82.5	64.5	81.2
6 weeks – 15/12/06	79.4	71.5	71.0	86.7	81.9	79.5	75.1	72.9	73.5	82.1	82.4	77.6	94.0	79.3	93.7
8 weeks – 29/12/06	82.8	81.3	78.9	96.4	86.0	84.4	76.1	73.8	86.1	92.9	90.1	87.9	104.5	82.6	107.5
10 weeks – 12/1/07	91.2	88.5	89.7	109.1	101.9	90.4	88.1	74.7	103.8	101.8	107.4	99.3	117.9	159.5	112.9
12 weeks – 26/1/07	97.5	98.0	91.9	122.8	107.1	96.8	93.8	111.5	130.8	106.8	120.9	114.1	128.3	163.3	127.8
14 weeks – 9/2/07	98.4	108.1	102.5	155.5	125.3	130.3	109.6	115.0	132.4	116.3	139.4	129.0	146.0	168.2	133.8
16 weeks – 23/2/07	100.1	112.4	104.1	169.8	135.4	150.8	118.2	123.8	134.8	130.2	141.6	141.0	155.8	186.5	142.4
18 weeks – 9/3/07	125.6	117.5	107.0	178.5	149.4	153.8	122.0	134.8	137.0	164.1	149.6	182.2	185.4	208.8	220.6
20 weeks – 23/3/07	138.3	132.9	122.0	191.0	168.8	166.0	148.4	147.1	149.3	181.8	163.0	193.5	227.4	223.7	241.1
22 weeks – 6/4/07	149.0	143.9	134.6	203.8	182.9	182.9	160.4	162.8	163.4	194.5	176.5	205.9	249.2	236.0	253.4
24 weeks – 20/4/07	154.0	148.9	140.6	211.8	187.9	187.8	163.4	166.8	167.7	198.5	180.5	211.9	263.2	268.1	270.4

Appendix 2: Final mean length (cm) of *O. niloticus* fed Feeds A, B, C, D and E for 168 days

	Feeds				
Replicates	A	B	C	D	E
1	16.79	18.07	16.75	18.02	19.92
2	16.54	17.82	17.02	17.75	19.87
3	16.42	18.16	16.89	18.45	19.54
Mean ± SD[i]	16.6 ± 0.17^{c}	18.0 ± 0.18^{b}	16.9 ± 0.14^{c}	18.1 ± 0.35^{b}	19.9 ± 0.21^{a}

i. Values with the same superscript are not significantly different ($P < 0.05$)

Appendix 3: Calculated mean weight (g) of *O. niloticus* fed Feeds A, B, C, D and E for 168 days

Date	Feed A	A± s.e.	Feed B	B± s.e.	Feed C	C± s.e.	Feed D	D± s.e.	Feed E	E± s.e.
03 Nov 06	43.00	1.91	42.97	0.22	42.80	1.62	43.87	1.81	43.97	1.38
17 Nov 06	59.43	3.52	65.00	5.07	54.90	1.37	64.70	0.96	66.50	4.85
01 Dec 06	61.50	2.10	69.10	4.12	68.00	0.70	71.60	4.06	76.07	5.80
15 Dec 06	73.97	2.72	82.70	2.12	73.83	0.66	80.70	1.50	89.00	4.85
29 Dec 06	81.00	1.14	88.93	3.76	78.67	3.78	90.30	1.45	98.20	7.85
12 Jan 07	89.80	0.78	100.47	5.45	88.87	8.41	102.83	2.39	130.10	14.80
26 Jan 07	95.80	1.96	108.90	7.56	112.00	10.7	113.93	4.07	139.80	11.80
9 Feb 07	103.00	2.81	137.03	9.35	119.00	6.88	128.23	6.68	149.30	10.10
23 Feb 07	105.53	3.62	152.00	9.95	125.60	4.88	137.60	3.70	161.60	13.10
9 Mar 07	116.70	5.38	160.57	9.06	131.27	4.68	165.30	9.43	204.90	10.30
23 Mar 07	131.07	4.79	175.27	7.91	148.27	0.64	179.43	8.88	230.73	5.29
6 Apr 07	142.50	4.22	189.87	6.97	162.20	0.92	192.30	8.56	246.20	5.25
24 Apr 07	147.83	3.90	195.80	7.98	165.97	1.31	196.07	9.10	267.23	2.12

Appendix 4: Absolute growth rate (g/day) of *O. niloticus* fed Feeds A, B, C, D and E

	Feeds				
Replicates	A	B	C	D	E
1	0.67	0.99	0.69	0.90	1.29
2	0.60	0.85	0.75	0.80	1.31
3	0.58	0.85	0.74	0.90	1.35
Mean ± se[i]	0.62 ± 0.02^{c}	0.90 ± 0.05^{b}	0.73 ± 0.02^{c}	0.87 ± 0.33^{b}	1.32 ± 0.02^{a}

i. Values with the same superscript are not significantly different ($P < 0.05$)

Appendix 5: Specific Growth Rate (%) of *O. niloticus* fed Feeds A, B, C, D and E

	Feeds				
Replicates	A	B	C	D	E
1	0.78	0.94	0.74	0.85	1.04
2	0.68	0.88	0.83	0.82	1.04
3	0.72	0.87	0.82	0.98	1.11
Mean ± se[i]	0.73 ± 0.05^{b}	0.90 ± 0.04^{b}	0.80 ± 0.05^{b}	0.88 ± 0.09^{b}	1.06 ± 0.04^{a}

i. Values with the same superscript are not significantly different ($P < 0.05$)

Appendix 6: Growth Efficiency (%) of *O. niloticus* fed Feeds A, B, C, D and E

	Feeds				
Replicates	A	B	C	D	E
1	1.25	1.47	1.40	1.46	1.74
2	1.22	1.47	1.43	1.33	1.75
3	1.22	1.50	1.32	1.54	1.80
Mean ± se[i]	1.23 ± 0.01^{c}	1.48 ± 0.01^{b}	1.38 ± 0.03^{c}	1.44 ± 0.06^{b}	1.76 ± 0.02^{a}

i. Values with the same superscript are not significantly different ($P < 0.05$)

Appendix 7: Feed Conversion Ratio of *O. niloticus* fed Feeds A, B, C, D and E after 168 days

	Feeds				
Replicates	A	B	C	D	E
1	7.1	3.7	4.5	4.5	2.6
2	10.8	4.9	5.2	5.0	2.5
3	7.2	5.4	6.7	5.0	2.3
Mean ± se[i]	8.37 ± 1.22^{c}	4.67 ± 0.5^{b}	5.47 ± 0.65^{c}	4.83 ± 0.65^{b}	2.47 ± 0.09^{a}

i. Values with the same superscript are not significantly different ($P < 0.05$)

Appendix 8: Feed Efficiency of *O. niloticus* fed Feeds A, B, C, D and E after 168 days

	Feeds				
Replicates	A	B	C	D	E
1	0.11	0.27	0.22	0.22	0.30
2	0.09	0.20	0.19	0.16	0.40
3	0.14	0.19	0.15	0.20	0.44
Mean ± se[i]	0.11 ± 0.03^{c}	0.22 ± 0.03^{b}	0.19 ± 0.02^{b}	0.19 ± 0.02^{b}	0.38 ± 0.04^{a}

i. Values with the same superscript are not significantly different ($P < 0.05$)

Appendix 9: Total Fish Production (kg) using Feeds A, B, C, D and E for 168 days

	Feeds				
Replicates	A	B	C	D	E
1	1.40	3.90	2.60	3.04	5.90
2	1.12	2.61	2.30	2.72	6.22
3	1.59	2.32	1.89	2.74	6.64
Mean ± se[i]	1.36 ± 0.23^{c}	2.94 ± 0.83^{b}	2.25 ± 0.35^{b}	2.83 ± 0.18^{b}	6.26 ± 0.37^{a}

i. Values with the same superscript are not significantly different ($P < 0.05$)

Appendix 10: Final mean wt, AGR, SGR, GE, FCR, FE, Buoyancy, Survival, Condition factor, Production, FC, TFC, Cost of TFC, Revenue and Profit in culturing *O. niloticus* for 168 days.

	Feeds				
Parameter	A	B	C	D	E
Final mean wt (g)	147.8 ± 3.9^{c}	195.8 ± 8.0^{b}	166.0 ± 1.3^{c}	197.0 ± 9.1^{b}	267.2 ± 2.1^{a}
AGR (g day^{-1})	0.62 ± 0.02^{c}	0.90 ± 0.05^{b}	0.73 ± 0.02^{c}	0.87 ± 0.33^{b}	1.32 ± 0.02^{a}
SGR (% day^{-1})	0.73 ± 0.05^{b}	0.90 ± 0.04^{b}	0.80 ± 0.05^{b}	0.88 ± 0.09^{b}	1.06 ± 0.04^{a}
GE (%)	1.23 ± 0.01^{c}	1.48 ± 0.01^{b}	1.38 ± 0.03^{c}	1.44 ± 0.06^{b}	1.76 ± 0.02^{a}
FCR	8.37 ± 2.11^{c}	4.66 ± 0.06^{b}	5.47 ± 0.65^{c}	4.83 ± 0.29^{b}	2.47 ± 0.08^{a}
FE	0.11 ± 0.02^{c}	0.22 ± 0.03^{b}	0.19 ± 0.02^{b}	0.19 ± 0.02^{b}	0.38 ± 0.04^{a}
Buoyancy (min.)	12.33 ± 1.52^{c}	3.70 ± 0.17^{a}	0.33 ± 0.01^{b}	0.03 ± 0.00^{b}	3.16 ± 0.04^{a}
Survival (% day^{-1})	43.3 ± 5.07^{c}	63.3 ± 6.96^{b}	61.1 ± 6.75^{b}	62.2 ± 4.47^{b}	93.3 ± 1.93^{a}
Condition factor	3.16 ± 0.12^{c}	3.20 ± 0.12^{a}	3.41 ± 0.04^{a}	2.93 ± 0.37^{a}	3.27 ± 0.08^{a}
Production (kg)	1.36 ± 0.23^{c}	2.94 ± 0.83^{b}	2.25 ± 0.35^{b}	2.83 ± 0.18^{b}	6.26 ± 0.37^{a}
FC per kg (GH¢)	0.08	0.35	0.27	0.51	0.32
TFC (kg)	12.0 ± 0.26	13.3 ± 0.60	12.0 ± 0.40	13.7 ± 0.07	15.2 ± 0.12
Cost TFC (GH¢)	0.96	4.70	3.20	7.00	4.00
Revenue (GH¢)	4.80	8.82	6.75	8.49	18.78
Profit (GH¢)	3.12	4.12	3.55	1.49	14.78

Values with the same superscripts are not significantly different ($P < 0.05$) (horizontal comparison).

AGR = Absolute growth rate, SGR = Specific growth rate, FCR = Feed Conversion ratio, FE = Feed efficiency, GE = Growth efficiency, FC = Feed cost, TFC = Total feed consumed.

Appendix 11: Bi-weekly temperature, pH and dissolved oxygen ± s.e. readings

Date	temp (ºC)	s.e.	pH	s.e.	DO (mg/L)	s.e.
03/11/06	28.27	0.15	8.50	0.06	7.80	0.06
17/11/06	27.00	0.06	8.00	0.06	8.07	0.07
01/12/06	26.53	0.03	7.50	0.00	8.00	0.06
15/12/06	26.13	0.07	7.50	0.06	8.10	0.00
29/12/06	26.10	0.06	7.50	0.00	8.13	0.03
12/01/07	27.13	0.09	7.50	0.12	8.07	0.07
26/01/07	26.03	0.03	7.50	0.06	8.10	0.06
09/02/07	29.30	0.06	8.00	0.00	7.67	0.03
23/02/07	27.50	0.00	7.53	0.03	7.80	0.00
09/03/07	29.00	0.12	8.70	0.06	7.67	0.03
23/03/07	30.07	0.07	8.10	0.06	7.50	0.06
06/04/07	30.60	0.00	8.23	0.12	7.43	0.03
20/04/07	29.50	0.06	8.50	0.00	7.50	0.00

Appendix 12: Initial weight (g) of *O. niloticus* fingerlings

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
48.1	60.5	40.2	38.5	56.5	43.5	59.1	54.0	31.1	41.4	56.2	40.2	49.4	39.7	59.4
54.6	25.4	48.1	46.5	55.5	35.4	41.8	50.2	46.5	34.5	47.1	48.5	56.3	54.1	57.9
48.2	59.7	51.6	56.6	58.3	39.9	53.8	45.5	41.3	45.0	44.3	28.3	44.4	56.3	57.2
47.4	41.8	55.5	45.6	26.4	34.3	25.9	49.7	45.8	52.5	49.5	45.3	47.0	43.6	56.3
52.5	24.0	53.1	51.6	56.8	39.6	43.5	54.2	35.9	45.2	46.6	54.5	58.7	36.5	55.3
43.1	22.2	50.2	44.4	58.7	47.4	55.3	42.9	30.7	52.2	39.9	42.5	50.0	31.3	56.4
43.3	37.8	45.3	31.3	45.7	37.3	55.6	40.5	43.6	41.2	40.9	43.6	44.8	54.9	48.2
38.8	22.0	54.7	46.3	35.9	21.5	51.5	29.9	40.1	57.9	56.5	42.5	47.7	38.9	50.0
43.5	29.1	44.1	32.9	25.3	23.9	51.9	39.3	55.7	43.2	30.4	36.8	52.5	50.6	56.5
36.5	33.2	42.5	52.1	33.5	38.1	30.3	38.6	30.9	20.2	44.9	33.5	47.6	53.9	56.2
41.5	41.4	39.8	37.6	50.6	46.5	56.6	42.8	40.0	37.3	22.6	26.7	51.5	50.1	49.3
34.7	57.7	54.4	23.8	48.1	53.2	39.6	52.4	46.0	50.8	27.3	21.4	52.0	35.9	44.8

Appendix 12 continued

26.2	50.7	42.2	45.9	54.2	48.8	51.3	46.1	33.3	47.7	35.1	30.2	39.1	21.2	41.8
52.2	50.4	43.2	56.6	53.9	54.6	33.6	38.8	37.1	50.4	46.6	52.2	44.4	25.7	53.3
44.9	28.1	42.6	34.5	39.5	35.8	43.2	47.2	53.4	37.5	40.4	52.8	44.7	52.0	33.7
39.9	30.3	40.3	53.2	52.7	55.5	52.5	35.1	49.3	31.6	54.4	27.8	43.6	30.8	51.0
46.3	40.2	29.3	58.5	55.0	53.9	36.9	55.9	54.8	37.8	51.6	36.4	45.3	41.3	41.8
49.2	46.0	40.0	32.5	40.2	49.7	54.8	25.7	39.3	47.2	38.5	55.7	28.2	56.6	41.2
49.7	31.9	53.9	56.9	38.3	41.2	53.0	35.5	45.0	46.3	55.7	28.5	59.1	26.6	37.2
49.5	50.0	44.6	49.6	40.4	33.2	22.6	31.3	52.3	31.6	61.3	51.6	50.6	46.3	44.4
32.3	26.8	43.9	42.2	46.8	57.5	40.3	29.3	50.9	37.3	31.7	23.9	42.1	22.8	41.7
50.4	46.5	52.3	49.2	43.2	38.5	32.0	28.7	44.3	26.8	31.9	30.2	35.6	54.5	34.8
50.8	28.0	52.6	56.2	48.0	54.5	30.5	57.7	29.2	35.3	33.4	33.6	30.9	39.6	25.1
51.4	30.2	44.3	46.0	54.4	44.2	21.2	35.0	54.6	24.0	27.6	49.3	38.0	32.3	21.8
43.1	57.0	43.5	47.5	43.0	48.9	52.0	26.1	59.5	24.8	31.2	42.3	30.1	22.3	32.0
46.5	45.4	53.9	50.0	52.1	35.7	25.1	30.1	34.1	55.1	23.4	45.5	24.6	56.5	28.9

Appendix 12 continued

51.7	43.3	25.1	54.3	47.1	36.3	30.6	35.2	40.0	49.6	23.8	42.2	51.7	47.6	25.6
51.5	49.8	36.9	37.0	51.2	44.9	42.5	54.7	42.2	47.3	56.6	33.3	57.2	59.4	26.7
36.6	49.2	55.9	58.1	42.0	35.3	30.4	32.9	43.6	57.6	53.8	53.7	58.2	56.3	53.7
35.0	44.4	57.0	57.2	49.5	55.8	21.0	37.7	51.3	38.7	39.4	58.5	52.2	44.4	59.9

Appendix 13: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 2 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
76.7	84.0	66.2	83.6	73.2	69.5	80.6	64.6	71.1	64.1	58.7	62.1	73.4	86.8	65.5
74.0	42.3	70.7	76.7	82.3	46.4	58.4	67.2	94.0	69.1	40.9	73.4	64.7	90.0	80.9
73.2	99.4	54.5	78.8	64.9	53.4	70.8	60.3	69.1	65.1	54.6	71.0	49.9	70.4	76.4
73.8	82.8	64.4	61.3	67.2	56.2	79.4	68.5	64.8	69.3	73.7	67.9	68.4	54.9	64.3
74.0	78.6	71.4	65.5	76.4	46.6	75.6	32.2	58.9	46.8	54.0	68.9	58.2	68.5	60.5
84.5	57.8	57.7	50.5	52.3	57.2	79.1	58.5	86.4	72.3	33.7	60.5	77.3	66.9	67.2
76.7	52.9	48.3	74.8	66.5	52.2	65.4	49.4	58.7	45.7	43.7	39.6	56.4	79.2	45.6
92.3	55.0	51.2	85.3	51.4	41.3	47.7	51.2	76.5	50.5	65.6	52.2	58.1	60.3	75.9
62.5	59.5	46.1	41.5	32.6	75.4	24.4	32.1	78.8	34.4	41.5	80.4	68.6	66.2	66.1
73.8	33.5	40.6	44.3	42.7	50.5	38.5	39.5	50.2	34.9	60.8	53.2	38.3	48.7	47.2

Appendix 14: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 4 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
95.2	75.3	95.6	77.2	80.4	76.6	103.3	66.7	89.8	54.5	90.5	68.2	66.5	93.94	92.2
80.5	56.9	79.4	113.9	71.0	66.0	101.7	65.5	80.0	92.0	62.5	88.0	80.5	80.34	91.5
95.9	66.5	76.2	93.1	60.8	58.4	99.6	77.3	104.8	93.1	83.6	75.2	83.1	73.34	95.5
83.3	80.2	76.2	81.9	72.7	65.7	90.1	56.1	92.5	74.3	69.0	61.5	68.1	107.44	66.7
87.4	45.0	33.5	100.5	56.3	74.4	48.3	67.4	83.4	41.9	36.7	71.1	67.6	54.34	73.3
77.7	92.5	77.5	50.2	30.7	54.2	101.9	64.4	75.6	71.4	71.0	94.9	61.0	72.74	81.5
79.0	39.9	74.5	58.1	84.2	68.4	83.0	84.6	49.9	68.0	46.3	53.2	63.2	56.14	54.7
83.9	58.4	57.9	41.9	54.7	49.6	74.7	70.9	61.9	58.3	43.6	40.3	71.1	52.24	77.7
74.7	49.5	67.9	60.4	54.7	50.9	54.8	69.0	60.1	69.2	26.3	58.4	55.2	33.84	77.5
67.5	83.8	55.2	54.7	55.2	45.7	54.5	52.4	46.9	49.4	46.3	27.7	29.0	93.94	66.0

Appendix 15: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 6 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2
92.3	62.8	81.7	109.8	42.5	56.0	92.5	53.4	63.5	98.3	73.1	95.5	82.7	83.3
93.5	76.3	81.2	59.1	86.0	88.8	95.4	79.5	124.8	53.4	71.7	101.8	85.2	69.0
106.5	101.7	74.2	93.9	84.4	95.8	88.6	85.1	96.2	93.4	71.3	34.4	88.7	41.9
109.3	36.7	72.2	105.6	85.5	88.5	104.8	96.8	114.4	82.7	85.2	59.2	79.7	93.2
92.2	86.4	81.9	55.1	62.0	80.3	110.5	69.0	76.3	65.2	71.6	99.8	88.9	99.5
88.2	100.0	57.7	84.5	78.3	81.3	98.3	36.9	49.0	46.8	73.5	76.0	82.0	77.1
82.7	88.8	78.3	69.7	67.8	101.2	76.5	88.3	94.6	75.4	62.9	83.9	71.6	99.7
106.2	118.7	82.6	109.5	92.7	70.0	104.0	79.0	80.4	90.2	72.3	73.8	91.0	117.4
68.6	67.9	76.0	76.9	42.5	71.1	95.0	68.9	62.8	54.6	48.7	74.4	47.9	58.8
100.6	54.4	65.3	57.1	73.2	61.5	71.2	71.9	105.1	74.6	79.8	77.6	75.4	78.7

Appendix 16: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 8 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
112.2	107.2	96.0	104.6	80.5	62.5	117.3	116.0	103.2	163.9	105.5	94.0	79.8	94.7	134.7
106.9	62.6	80.6	92.1	97.0	64.1	122.7	80.0	107.4	162.0	75.6	119.3	79.6	100.8	110.8
102.0	76.6	76.7	80.6	97.3	68.6	106.0	83.7	105.9	84.6	75.8	115.9	97.2	92.6	67.4
119.2	112.6	72.1	112.8	65.4	73.4	107.0	100.2	67.7	99.1	94.8	82.8	99.7	88.8	73.8
140.1	51.3	70.4	63.2	47.9	111.4	99.3	69.8	124.7	68.9	60.1	67.4	86.3	75.3	95.4
92.9	53.2	88.4	89.5	93.6	110.2	93.7	39.1	62.3	38.0	73.8	72.6	83.8	123.5	105.4
98.8	102.8	81.2	115.5	63.5	72.7	116.1	72.1	109.0	71.9	93.5	83.8	89.6	58.3	98.0
100.2	52.0	56.7	115.1	117.8	127.5	102.1	56.5	81.4	50.6	79.5	64.6	77.4	76.1	86.7
73.2	66.9	82.0	99.5	94.4	67.3	119.0	65.8	97.9	70.5	49.9	85.7	62.1	57.7	77.1
99.7	102.3	56.5	56.1	55.8	86.4	91.6	54.3	104.1	51.4	80.1	92.9	70.0	92.0	52.1

Appendix 17: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 10 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
156.2	82.1	90.4	139.8	87.1	74.0	109.7	91.0	110.2	168.1	90.9	48.0	188.1	109.1	108.2
137.1	132.7	96.9	102.4	107.7	85.7	119.3	64.9	115.8	175.3	67.2	133.7	195.7	116.7	147.9
120.9	106.8	106.6	104.0	73.9	75.6	142.4	84.1	133.6	59.8	114.0	90.9	184.4	100.2	82.4
113.8	45.2	84.4	105.8	107.8	115.8	102.0	90.2	124.0	99.6	90.3	131.3	157.2	104.2	120.9
132.3	56.8	81.8	80.2	64.1	118.2	108.3	42.7	120.5	84.5	73.7	101.2	155.4	83.8	113.1
111.9	89.3	101.8	109.1	89.3	75.8	106.1	53.2	142.2	74.3	94.1	107.8	172.4	119.0	113.6
114.8	127.8	80.1	95.9	130.4	99.3	104.0	85.6	75.6	106.8	81.7	111.9	186.6	130.2	128.2
83.8	73.4	85.5	118.1	59.7	121.5	132.1	98.9	118.1	98.3	102.4	96.9	93.1	92.8	107.0
91.4	107.4	55.0	117.6	107.7	57.3	115.4	81.0	57.1	116.6	84.0	92.9	177.6	100.5	51.5
116.4	90.5	98.9	44.6	57.1	80.5	90.0	55.5	93.9	54.7	98.4	78.8	84.0	62.5	101.0

Appendix 18: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 12 Weeks

E1	A1	C1	D1	A2	B3	A3	C2	B1	C3	A3	D3	E1	B2	D2
148.7	107.9	84.8	156.9	112.7	91.6	120.6	75.8	147.6	189.2	87.2	100.9	203.0	156.7	110.9
148.6	78.3	104.2	124.9	92.3	85.5	155.5	104.2	121.1	184.4	103.5	130.0	165.5	138.0	151.2
118.6	111.2	87.6	110.4	111.6	93.2	130.1	87.6	167.5	101.3	89.5	136.4	186.9	116.3	144.8
124.2	110.6	101.8	106.0	90.9	86.4	156.3	101.8	129.1	66.9	87.8	126.1	177.6	126.8	121.5
124.2	96.8	99.4	116.5	140.1	128.9	128.5	99.4	132.9	104.2	104.3	102.5	161.8	142.3	142.0
150.3	91.3	106.8	82.5	123.1	132.7	128.2	189.2	128.9	87.6	88.4	122.8	178.5	93.7	107.7
116.6	105.2	96.7	101.8	59.8	108.7	138.0	184.4	132.7	101.8	94.6	87.1	111.2	80.1	105.7
87.1	90.6	58.3	86.1	67.1	79.3	127.0	101.3	108.7	99.4	95.7	98.9	167.4	103.4	135.0
127.0	84.2	110.1	134.5	60.3	103.4	98.5	66.9	79.3	189.2	87.8	141.1	145.7	57.8	114.8
138.1	98.8	88.7	47.9	122.5	57.8	95.0	104.2	79.8	184.4	80.0	94.7	134.9	55.5	75.5

Appendix 19: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 14 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
166.3	88.9	117.5	169.4	145.7	105.3	155.4	101.8	203.0	194.3	128.1	139.4	220.7	166.0	151.7
171.5	160.5	92.6	117.0	123.3	90.9	151.3	120.5	189.5	126.7	109.1	146.1	137.7	127.8	164.9
144.9	91.0	132.7	149.5	84.1	166.0	173.0	95.6	116.4	123.7	98.8	153.2	129.5	151.8	179.4
132.0	152.9	105.3	108.2	133.5	127.8	112.7	135.7	177.8	125.5	94.2	138.8	152.2	155.7	167.8
176.3	70.7	118.2	121.8	100.8	151.8	133.2	108.3	151.1	100.6	111.7	111.4	149.8	135.6	91.8
145.5	152.9	123.9	81.6	62.7	155.7	120.2	121.2	163.2	140.7	95.5	112.4	186.3	121.2	138.1
132.2	78.3	110.1	167.6	134.8	135.6	131.0	126.9	152.6	113.3	109.4	148.1	191.5	129.2	136.5
129.8	72.4	96.8	72.8	121.7	121.2	133.4	126.9	138.0	126.2	99.8	115.8	152.0	119.8	126.9
136.9	55.4	100.7	126.2	76.2	129.2	112.9	113.1	126.8	131.9	96.1	91.0	196.3	74.5	112.5
124.1	60.9	98.6	49.2	98.0	119.8	114.4	99.8	136.9	140.7	82.5	134.1	165.5	71.4	124.7

Appendix 20: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 16 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
181.7	127.2	119.4	180.5	135.7	112.3	159.6	125.0	195.2	145.1	81.0	201.0	240.9	187.1	134.9
155.6	108.0	132.6	162.3	145.2	105.1	126.3	130.1	175.0	136.0	127.5	110.9	166.5	124.7	179.4
122.3	58.5	80.3	154.7	136.1	175.0	187.0	121.0	184.4	148.8	110.1	218.5	176.4	144.2	175.1
183.0	133.5	122.3	110.6	108.1	184.4	139.0	133.8	154.7	128.6	115.8	143.9	175.6	133.4	165.5
135.0	106.1	130.1	128.2	133.4	154.7	140.2	113.6	144.6	130.9	104.6	110.1	189.9	172.3	126.7
136.2	119.3	121.0	105.4	114.2	144.6	149.2	115.9	175.4	128.3	106.8	146.3	203.0	121.5	146.9
145.2	98.4	133.8	147.8	89.4	175.4	145.7	113.3	161.1	140.0	110.6	138.7	155.0	130.8	139.1
220.9	89.5	113.6	74.4	85.0	187.1	133.6	132.6	155.1	133.2	94.9	127.8	202.7	106.6	137.4
146.5	57.5	115.9	111.5	83.2	124.7	125.5	122.3	166.4	129.5	96.4	110.0	165.2	115.1	115.6
131.6	103.2	113.3	126.7	93.5	144.2	118.0	130.1	185.8	127.6	93.5	102.9	189.7	118.0	95.6

Appendix 21: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 18 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
212.6	100.4	136.5	166.1	143.9	129.2	295.1	178.4	182.4	142.3	88.5	221.7	188.8	191.2	173.9
176.9	150.5	122.1	178.6	152.9	119.7	214.7	131.2	167.4	129.7	113.7	205.5	210.5	160.6	169.9
137.7	166.7	136.4	179.9	143.9	107.0	223.5	141.5	187.9	130.9	129.0	140.4	219.5	160.6	181.8
156.8	109.2	118.1	162.1	156.2	123.3	245.3	127.1	201.7	131.1	113.1	150.8	203.7	139.3	146.3
170.2	144.0	127.3	140.4	88.7	201.2	223.9	141.4	196.8	131.1	107.9	215.3	207.2	166.3	145.6
138.5	131.2	114.7	168.8	113.4	170.6	213.7	123.1	176.8	132.1	99.7	169.5	202.0	180.4	129.3
192.4	126.7	115.9	176.5	105.3	170.6	224.7	132.3	169.6	151.5	125.6	193.4	221.5	130.9	176.5
233.7	108.8	116.1	146.1	100.3	149.3	210.6	132.3	188.9	137.1	102.5	179.8	216.0	119.3	133.6
213.6	121.0	116.1	156.9	89.2	176.3	176.6	119.7	166.1	151.4	91.9	195.7	206.0	119.2	121.4
221.3	97.8	117.1	165.6	80.4	190.4	177.8	120.9	147.3	133.1	106.4	149.6	213.1	126.6	117.8

Appendix 22: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 20 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
243.6	150.5	158.5	178.5	163.9	139.8	296.1	153.6	225.3	112.1	140.8	237.3	221.1	193.9	159.1
250.6	162.6	168.2	174.1	166.8	136.0	252.0	106.3	207.8	152.2	129.4	188.3	229.8	212.0	190.3
239.5	178.6	165.8	191.5	167.2	143.7	244.7	158.5	193.4	141.0	126.5	235.7	212.4	171.4	195.3
205.0	154.0	153.3	194.4	128.5	193.9	245.7	168.2	166.6	122.1	108.7	228.5	234.2	192.2	183.9
153.0	177.2	156.7	178.5	125.0	212.0	234.4	165.8	198.9	133.3	119.2	212.1	228.3	154.4	145.3
143.6	137.7	156.7	183.6	160.4	171.4	237.1	153.3	217.0	164.5	123.0	184.7	218.5	163.1	146.7
296.1	124.7	146.2	189.7	121.4	192.2	228.6	156.7	176.4	174.2	112.3	190.5	206.2	153.1	143.5
252.0	108.2	135.0	168.5	100.8	154.4	209.4	146.2	197.2	171.8	127.8	175.8	217.4	148.1	153.5
244.7	97.6	116.1	174.4	105.0	163.1	226.5	135.0	159.4	159.3	127.5	139.8	235.5	164.0	140.6
245.7	92.1	127.3	184.8	89.6	153.1	236.7	127.3	168.1	162.7	104.5	142.2	233.9	135.6	171.7

Appendix 23: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 22 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
276.7	183.4	151.3	194.0	181.3	125.0	285.7	159.8	220.5	154.5	129.3	239.5	240.5	187.8	211.6
287.0	192.3	174.7	185.0	176.1	187.8	242.6	154.5	237.8	170.4	123.0	191.4	236.7	219.2	216.0
196.9	169.4	136.3	188.1	176.0	219.2	259.1	170.4	196.8	161.3	134.2	238.8	247.4	173.2	168.0
245.5	163.1	154.5	181.0	132.7	173.2	240.4	161.3	228.2	156.4	139.5	190.4	232.2	196.0	175.3
241.7	139.5	170.4	176.5	111.8	196.0	246.7	156.4	182.2	169.1	136.5	213.6	219.4	200.0	159.0
252.4	149.5	161.3	229.6	133.6	200.0	234.5	169.1	205.0	164.5	148.5	233.4	242.9	162.1	176.0
237.2	119.8	156.4	234.0	146.3	162.1	243.9	164.5	209.0	165.7	122.4	186.4	241.0	161.0	167.0
247.9	123.9	169.1	186.0	98.5	189.1	238.4	165.7	171.1	151.3	139.4	202.9	255.6	160.0	170.1
246.0	88.4	164.5	193.3	106.4	180.2	288.7	151.3	198.1	174.7	135.9	179.9	230.0	189.1	163.0
260.6	160.5	165.7	177.0	176.1	196.0	253.7	174.7	189.2	166.5	137.0	183.0	214.0	180.2	158.5

Appendix 24: Weight (g) of *O. niloticus* fed on Feeds A, B, C, D and E after 24 Weeks

E1	A1	C1	D1	A2	B3	E3	C2	B1	C3	A3	D3	E2	B2	D2
276.6	161.7	176.8	191.7	139.3	213.0	343.4	165.6	246.7	189.3	132.0	250.6	338.2	190.0	215.1
287.3	126.0	172.2	142.4	183.7	204.0	288.6	164.5	233.1	209.5	141.7	255.7	290.2	202.6	214.6
203.8	193.7	140.2	172.2	186.2	251.1	299.6	148.1	224.1	152.2	141.3	211.8	322.7	208.5	174.1
273.3	150.5	180.0	121.4	182.8	208.6	287.3	154.3	271.2	128.7	152.9	220.4	267.9	214.0	189.0
261.8	200.5	175.1	111.7	186.9	152.9	281.9	194.8	228.7	171.1	145.6	215.4	278.9	192.9	219.6
252.2	165.6	182.5	173.0	141.7	174.3	301.0	161.8	173.0	166.5	153.0	240.2	266.6	177.1	187.8
250.2	179.1	165.4	155.5	153.8	160.3	262.3	177.6	194.4	134.5	147.6	266.0	261.2	223.1	228.4
255.4	138.7	163.4	141.5	120.4	182.6	257.7	171.5	180.4	174.3	135.7	258.9	280.3	227.4	145.4
255.9	166.6	187.1	157.1	120.9	180.6	259.7	166.9	202.7	169.4	141.9	247.0	241.6	206.2	188.4
276.6	143.6	170.3	158.1	115.3	162.6	235.5	134.9	200.7	176.8	134.1	217.4	237.0	187.9	175.6
287.3	118.4	181.2	164.0	106.4	200.8	265.2	174.7	182.7	159.7	139.3	213.4	239.0	243.1	180.7
203.8	103.0	178.5	121.4		215.4	247.7	169.8	220.9	157.7	146.4	166.8	322.7	209.1	208.2

Appendix 24 continued

273.3	177.4	111.7	184.5	253.0	177.2	233.1	181.4	144.7	167.3	267.9	189.7	173.6
261.8	161.2	173.0	147.7	226.6	160.1	224.1	164.6	133.7	172.7	278.9	176.6	173.5
252.2	142.4	155.5	154.6	232.2	158.1	271.2	175.5	150.2	139.4	266.6	146.9	187.3
389.6	165.8	141.5	213.1	246.2	181.8	228.7		109.2	147.7	261.2	139.3	175.1
203.8	165.3	157.1		242.5	165.0	173.0				280.3	134.9	153.2
273.3	150.9	158.1		265.3	175.9	194.4				241.6	113.7	152.2
261.8	134.7	164.0		304.8		180.4				237.0		142.8
252.2	169.4	173.6		249.0		202.7				239.0		125.3
250.2	129.0			220.0		200.7				237.0		
255.4	126.1			258.4		182.7				239.0		
255.9				278.9		220.9				322.7		
271.5				247.5						267.9		
287.3				288.6						278.9		

Appendix 24 continued

255.9	299.6	266.6
276.6	287.3	261.2
	281.9	280.3
	262.3	

Appendix 25: Length (cm) of *O. niloticus* fed Feeds A, B, C, D and E after 168 days

A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3
17.7	16.4	16.5	19.6	18.0	19.4	17.2	17.2	17.5	19.5	19.5	19.5	21.0	23.0	23.7
15.7	18.1	17.1	18.0	19.0	18.7	17.7	17.0	19.0	18.0	19.1	19.8	20.7	22.1	20.5
17.9	18.0	16.6	19.0	18.6	20.1	15.3	16.5	16.0	19.4	17.4	18.6	18.9	20.5	20.4
16.8	18.0	17.0	18.6	19.8	19.0	17.6	17.5	15.0	17.2	18.4	19.1	20.3	20.4	20.0
18.5	18.3	16.2	19.8	18.4	16.3	17.0	18.1	17.7	17.9	19.1	18.5	20.3	20.0	19.9
16.8	16.4	17.1	18.4	17.4	17.3	17.7	17.0	17.0	19.4	18.8	19.5	20.0	19.9	20.5
18.0	16.9	16.8	17.4	18.8	17.0	17.0	17.2	16.2	18.8	19.8	20.0	20.1	20.5	19.5
16.3	15.2	16.3	18.8	19.5	18.1	16.2	17.7	17.6	18.5	16.6	19.9	20.5	19.5	19.0
17.5	15.2	16.5	19.5	18.6	17.5	17.6	17.0	16.9	18.4	18.0	19.5	20.2	20.3	19.3
16.5	15.4	15.9	18.6	18.0	17.1	16.9	16.2	17.5	18.5	17.6	18.8	20.0	20.3	18.5
15.5	14.4	16.4	18.0	20.0	18.9	17.5	17.6	17.0	17.8	17.7	18.9	19.9	20.0	19.9
14.3		16.5	20.0	18.6	19.3	17.0	16.9	17.2	17.6	18.5	17.2	20.5	20.1	19.0
		16.4	18.6	17.9	18.2	17.2	17.5	16.8	17.7	17.7	16.8	19.5	20.5	19.1
		15.9	17.9	16.1	16.2	16.8	17.0	15.2	18.5	17.3	17.3	19.0	20.2	18.5
		17.0	16.1	16.3	18.0	15.2	17.2		17.7	17.8	15.8	19.3	19.9	18.5
		14.5	16.3	15.8	19.4	16.8	16.8		17.3	17.5	16.0	27.3	20.5	18.8
			15.8	15.5		16.5	15.2		17.8	16.6		19.9	19.5	19.5
			15.5	14.5		16.0	16.8		17.5	16.3		19.0	19.0	19.5
			14.5			15.3			16.6	16.0		19.1	19.3	20.2
			18.6			16.6			16.3	15.2		18.5	18.5	19.8
			18.0			14.8						18.5	19.9	17.5
			20.0									18.8	19.0	19.6
			18.6									19.5	19.1	18.6
												19.5	18.5	19.4
												20.2	18.5	20.0
												19.8	18.8	19.4
												17.5	19.5	18.6
													19.6	19.4
														20.1

Appendix 26: Cost of Feed A

Ingredient	Quantity (kg)	Cost (GH¢)
Wheatbran	25	2.00
TOTAL	**25**	**2.00**

Cost per kilogram of Feed A = 2/25 = 0.08

GH¢ 0.08

Appendix 27: Cost of ingredients used in formulating Feed B

Ingredient	Quantity (kg)	Cost (GH¢)
Wheatbran	16.00	1.28
Fishmeal	8.00	5.60
Soybean cake	0.00	0.00
Maize	0.50	0.13
Palm oil	1.00	1.00
Broiler premix	6×10^{-5}	0.14
AD premix	6×10^{-5}	0.27
Lysine	3×10^{-5}	1.14
Methionine	3×10^{-5}	0.27
TOTAL	**25.68**	**9.83**

Cost per kilogram of Feed B = 9.83/25.68 = 0.38

GH¢ 0.38

Appendix 28: Cost of ingredients used in formulating Feed C

Ingredients	**Quantity (kg)**	**Cost (GH¢)**
Wheat bran	16.00	1.28
Fishmeal	0.00	0.00
Soybean cake	8.00	4.00
Maize	0.50	0.13
Palm oil	1.00	1.00
Broiler premix	6×10^{-5}	0.14
AD premix	6×10^{-5}	0.05
Lysine	3×10^{-5}	0.11
Methionine	3×10^{-5}	0.14
TOTAL	**25.68 kg**	**6.85**

Cost per kilogram of Feed C = 6.85/25.68 = 2.70

GH¢ 2.70

Appendix 29: Cost of Feed D

Ingredients	Quantity (kg)	Cost (GH¢)
GAFCO FEED	45	23.00
TOTAL	**45**	**23.00**

Cost per kilogram of Feed D = 23/45 = 0.51

GH¢ 0.51

Appendix 30: Cost of ingredients used in formulating Feed E

Ingredient	Quantity (kg)	Cost (GH¢)
Wheatbran	16.00	1.28
Fishmeal	4.00	2.80
Soybean cake	4.00	2.00
Maize	0.50	0.13
Palm oil	1.00	1.00
Broiler premix	6×10^{-5}	0.14
AD premix	6×10^{-5}	0. 27
Lysine	3×10^{-5}	1.14
Methionine	3×10^{-5}	0.03
TOTAL	**25.68**	**8.79**

Cost per kilogram of Feed E = 8.79/25.68 = 0.34

GH¢ 0.34

Appendix 31: **Calibration of Dissolved Oxygen meter**

PRINCIPLE

DO meter is calibrated by immersing the probe into a zero oxygen solution followed by setting the meter reading to zero while stirring gently for approximately 2 minutes until the reading is stabilized.

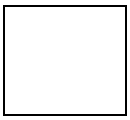
REAGENT

2 g of Sodium Sulphite is added to 100 ml of distilled water to form zero oxygen solution.

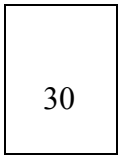
Appendix 32: Pearson Square Method of Ration Formulation

This method is generally used when two foodstuffs are required to formulate a diet with a definite percentage of a specific nutrient (e.g. 30 % crude protein). For instance, to formulate a 30 % crude protein feed from maize (9 % protein) and fishmeal (60 % protein). The procedure involves 6 steps:

Step 1: Draw a square



Step2: In the center of the square, put the protein content desired in the final mixture.

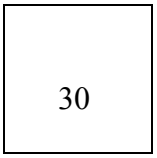


Step3: At the upper left-hand corner write maize with its protein content (9 %).

Step4: At the lower left-hand corner write fishmeal and its protein content (60 %).

Step5: Subtract diagonally across, the smaller from the larger and the results written at the right hand corners.

Maize 9 % 30 parts of maize



Fishmeal 60 % 21 parts of fishmeal

51

The results obtained indicate that 30 parts of maize and 21 parts of fishmeal are needed to make a diet containing 30 % crude protein. The sum of 30 and 21 equals 51 parts.

Step6: These are then converted into percentages as follows:

Maize = $\frac{30}{51}$ x 100 = 58.8 %;

Fishmeal = $\frac{21}{51}$ x 100 = 41.2 %

This means that to formulate a feed of 30 % crude protein from maize and fishmeal, 58.8 % (or 58.8 kg) maize and 41.2 % (or 41.2 kg) fishmeal should be mixed together.

For the current study, to formulate Feed E at 30 % crude protein from soybean cake (48 % protein), fishmeal (60 % protein), wheat bran (18 % protein) and maize (9 % protein), the steps involved first separating the ingredients into 2 groups (Protein Concentrate and Carbohydrate concentrate) and specify the proportions each group require in the mixture in order to determine the average protein content. Thus, fishmeal and soybean cake were mixed together in the ratio 1:1 to form the protein concentrate whereas maize and wheat bran were mixed in the ratio 1:32 to form the carbohydrate concentrate. Therefore, the protein in the carbohydrate concentrate will be:

Wheat bran = 32 x16= 512

Maize = 1x 9 = 9

Total = **521**

Therefore, the average protein content of the carbohydrate concentrate is 521 divided by 33, which equals to 15.52 %. Similarly, the protein concentrate will be:

Soybean cake = 1 x 48 = 48

Fishmeal = 1x 60 = 60

Total = **108**

The average protein content of the protein concentrate is 108 divided by 2, which equals to 54 %. The Pearson square method can now be applied as explained in steps 1-6 above. i.e.

Fishmeal/soy cake 54 % — 14.48 parts of wheatbran/maize

30

Wheatbran/maize 15.52 % — 24 parts of fishmeal/soy

38.48

Therefore, fishmeal/soy cake = $\frac{14.48}{38.48}$ x 100 = 37.63

Fishmeal = 18.82, Soybean cake = 18.82

Similarly, wheat bran/maize = $\frac{24.00}{38.48}$ x 100 = 62.37

Wheat bran = 60.48, Maize = 1.89

These calculated weights are for preparing a 100 kg weight feed. However, for the study, feeds were formulated in 25 kg weights at a time. Therefore, the calculated quantities were divided by 4. Thus, fishmeal will be 4.71 kg (round up to 5 kg), soybean cake 4.71 kg (round up to 5 kg), wheat bran 15.12 kg (round up

to 16 kg) and maize 0.47 kg (round up to 0.5 kg). The quantities were round up to take care of errors and to make sure the 30 % crude protein level was maintained after processing.

Appendix 33: t-test on absolute growth rates

Regression	Hopkin	
Mean	0.888	1.32
Variance	0.07097	0.0039
Observations	5	5
Pearson correlation	0.87907	
Hypothesized mean difference	0	
Df	4	
t-stat	-4.52263	
P(T ≤ t) one-tail	0.005319	
t Critical one-tail	2.131847	
P(T ≤ t) two-tail	0.010637	
t Critical two-tail	2.776445	

P-value = P(T > t) two-tail

= 1 - P(T ≤ t) two tail

= 1 - 0.010637

= 0.989363 > α = 0.05

Therefore, the difference is significant