

DEVELOPMENT OF AN INTEGRATED POULTRY/FISH
HUSBANDRY AND MODELLING OF RELEVANT
ENVIRONMENTAL PARAMETERS

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May 2009

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A THESIS in the Department of Agricultural Engineering,
School of Engineering and Engineering Technology,

Submitted to the School of Postgraduate Studies,
Federal University of Technology, Akure.

In Partial Fulfillment of the Requirements of Doctor of Philosophy (Ph.D) Degree in
Agricultural Engineering (Farm Structures and Environmental Control Option)
Federal University of Technology, Akure, Ondo State, Nigeria

DEDICATION

**This research work is dedicated to the glory of God and
Memories of my Late Parents**

ACKNOWLEDGEMENT

I give all praises and honour to almighty God, the source of my strength. The Lord by His mercies has enabled me to reach a successful completion of this programme in spite of all challenges and inadequacies.

My heartfelt gratitude goes to my amiable and supportive supervisor, Prof. A.S. Ogunlowo. He always gave me a sense of direction and his fatherly love is beyond description. My appreciation goes to my co-supervisor, Engr. Dr. M.O. Alatise who is always there for me to offer useful contributions and openheartedness, which helped me out in times of difficulties. The special love I enjoyed from Prof. J.O. Afolayan, who is also my co-supervisor, is worthy of appreciation. In spite of his tight schedules, he always created time to render good advice and constructive criticisms.

I am particularly grateful to our most senior members of staff in the Department, Prof. O.C. Ademosun and Prof. A.A. Olufayo for their love and encouragement. I am indebted to all staff of Agricultural Engineering, FUTA for their unflinching support and prayers in the course of my research work. Most importantly, I want to thank Prof. L.A.S. Agbetoye who used encouragement efforts to make sure that I complete the research work and become a PhD holder. I equally appreciate the materials he provided for the completion of this work. I appreciate the contributions of the following people that have helped in achieving success in my Ph.D programme: Dr. J.T. Fasinmirin, Dr. P.G. Oguntunde, Dr. Y. Mijinyawa, Prof. T.O. Kadeba, Dr. A.E. Ajayi, Prof. B.A. Adewumi, Dr. A.O. Owolabi, Dr. O.J. Olukunle, Dr. C. Arum, Mrs F. Uchebenu, Mrs D.T. Akintokunbo, Mr. A.A. Adesina, Pastor M.A. Omotoyinbo, Mr. A. Agboola, Engr. O.O. Odubango, Dr. S.O. Agele, Engr. A.S. Oyerinde, Engr. J. Isa, Engr. A.O. Akinola, Engr. Adebayo Babatunde and Engr. A.P. Olalusi. Also I appreciate the contributions of Prof. O.A. Fagbenro, Prof. E.A. Fasakin, Dr. O.T. Adebayo and Mr. Mike Ojuola in the Department of Fisheries and Aquaculture Technology, Prof. E.A.O. Laseinde, Mr. Ogunraku V.A. and Mr. Yusuf I.O. in the Department of Animal Production and Health, Dr A.F. Ayesanmi in the Department of Industrial Chemistry. My best regards to all my students past and present for their love and support at all times.

Lastly, I appreciate members of my family for their love, understanding and support at all times. My special thanks go to my loving wife, Mrs Caroline Adejoke Falayi who is both my mother and friend. I also appreciate the contributions of my God-given children: Ayodeji, Omowumi, Adesola, Olaniyi and Temitope for staying healthy throughout the period of this research work. I express my profound gratitude to my elderly sisters and Brother, Mrs Beatrice Babalola, Mr Ayodele Falayi, Mrs Abigail Ofere who always show

love and understanding. I am grateful to my in-laws; Mr and Mrs Olubu Francis Elero, Mr Ojo Olubu, Lt Kolawole Elero, Mr Ilori Elero, Mrs Beji 'Yemi and Mr Segun Elero for their love and prayers.

I specially thank the following good people: Engr. Ojo Taiwo Kareem, Engr. T.A. Falade, Mr E. Ajayi, Barrister Dapo Agbede, Mr. Joseph Olususi, Mr Olaleye Ologe, Mr Samuel Arogunjo, Mr. Emma Edeh, and Mr Sola Arobiagba for their encouragement.

ABSTRACT

The need to find alternative but productive means of managing animal waste in modern agriculture cannot be over-emphasised. One important means of managing these wastes is through conversion to important use either as animal feeds or as manures. Fish farming can be combined with poultry, animal husbandry and irrigation practices, which can lead to higher production and net profits. This practice is called integrated fish farming or integrated aquaculture. The integration of animal husbandry, especially poultry, with fish farming in a small scale results in the production of organic manure for the fertilization of the fish pond to increase the production of the natural food organism (planktonic algae) for fish to eat. In some cases, the poultry wastes are used as direct food by some fishes without supplementary feeding; such species include the Nile tilapia and African catfish

Therefore, the study was aimed the development of an integrated poultry/fish housing unit that will promote productive poultry and fish farming in the study area and as well develop a model using environmental parameters that would affect poultry birds in a vertical integrated poultry/fish unit.

An integrated poultry/fish housing unit was designed and constructed such that poultry droppings were made to drop into the tanks directly and used as fertilizer for rearing the African catfish, *Clarias gariepinus*. The set-up was made of four concrete tanks (1m x 1m x 1m) on which three wooden battery cages were mounted except the fourth pond which served as the control. The ponds were stocked with twenty (20) juvenile *Clarias gariepinus* of about 20 g each. A single factor experiment was adopted with randomized complete block design (RCBD). There were four treatments and two replicates, Fish in tanks 1, 2 and 3 were fed with droppings from one broiler, two broilers and three broilers, respectively. While fish in tank 4 were fed with a commercial fish feed to serve as control. A total of six birds (4 weeks old) and 80 juvenile *C. gariepinus* were used. This experiment lasted 168 days.

During this period, environmental parameters were monitored and the effects of poultry droppings on the growth of the fish were determined. The micro-climate studies were carried out on an integrated poultry/fish unit and the response of the poultry birds to the environmental factors was carefully analysed. A model of the influence of environmental factors on the development of the birds was developed. The developed model was calibrated and validated using regression model diagnostic tools like leverages, cooks distance and probability plots. The experiment was repeated for three consecutive years, 2004 (April – September), 2005 (February – August) and 2006 (March – September).

The highest Weight gain (WG) value was obtained in tank 4 and the least in tank 3. The average daily growth rate (ADG) and specific growth rate (SGR) data followed the same trend as WG. Weight gain, ADG and SGR decreased linearly as the dropping levels increased. The fish growth indices data obtained were compared with the control and they were all significant ($p = 0.05$). Weight gain in fish in tank 1 increased at a rate of 10.85 g/week up to the 15th week after stocking. Thereafter, weight gain increased constantly at a rate of 86.8g/week up to the 20th week after stocking and thereafter decreased to a rate of 136.56 g/week up to harvest period. In tank 2, the weight of the fish increased at 7.47 g/week up to 8th week. Thereafter, the weight gain increased at a rate of 24.88 g/week to 16th week and then decreased to a rate of 42.75 g/week up to harvest period. The same trend was observed in tank 3 but the weight gain increased at a rate of 8.06 g/week up to the 4th week and then at a constant rate of 10.89 g/week to the 16th week. Thereafter, there was decrease in the rate of weight gain to a rate of 32.36 g/week up to harvest period. Tank 4, which served as the control, showed a different trend in the growth of the fish, where there was a weight gain at an increasing rate of 12.90 g up to the 18th week after stocking. Thereafter the rate of weight gain decreased to a rate of 147.22 g/week up to harvest period. A log-log plot of the weight of birds and time is a straight line graph which suggests the growth of birds as a

power of time similarly observed for other studies. The study showed the possibility of effective poultry waste management technique which ensured that nothing is wasted and waste handling problem is greatly minimised.

Pollution of water in tanks resulting from the poultry droppings adversely affected the water quality and growth of the fish in this study. Increase in the volume of droppings led to increase in the Bio-Chemical oxygen demand and Chemical Oxygen demand of the tank water which consequently led to a decrease in the dissolved oxygen concentration. Water turbidity also increased with increased volume of droppings. Other water quality parameters such as conductivity, chloride and pH values were within the acceptable requirement values for fish culture.

The developed model is a good engineering solution for prediction of poultry birds' development based on environmental influence in a humid tropical environment and findings from this study will be useful for adoption and careful planning of an integrated poultry/fish husbandry for optimum productivity.

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1. INTRODUCTION

1.1 General Introduction

In many parts of the world, fish have provided an important part of people's diet for centuries. The increasing per capita consumption of fish is partially due to consumer's demand for healthy diet and the growing recognition that the fatty acid content of fish provides health benefit to man. The growth rate of the world's human population has called for increased harvest of fish and fisheries products from marine and inland waters (Woynarovich 1979). Chandrasoma (1988) observed that during the last hundred years, fish catches have increased rapidly due to improved technologies. The need to increase fish production by fish farming is urgent.

Fish farming can be combined with poultry, animal husbandry and irrigation practices, which can lead to higher production and net profits. This practice is called integrated fish farming or integrated aquaculture. The integration of animal husbandry, especially poultry, with fish farming in a small scale results in the production of organic manure for the fertilization of the fish pond to increase the production of the natural food organism (planktonic algae) to be eaten by the fish. In some cases, the poultry wastes are used as direct food by some fish without supplementary feedings, such species include Nile Tilapia (FAO, 1996).

There are various methods of integrating poultry with fish farming. Some designs give room for the poultry house to be sited on a land near the pond and the poultry waste/ manure is transferred into the pond manually. While another design sites the poultry directly on the pond. Literature regarding poultry/fish integration generally relates to battery or deep litter in which the birds are typically fed on complete diets in pelleted or mash form and the

manure used as feed (Little and Muir, 1987). Manure is packed into the pond to fertilize it for the fish to feed. Not all fish are carnivores; therefore, not all can feed on manure. The herbivores rather pick waste supplemental feeds from the birds' meal only.

Integrated fish farming is regarded by aquaculturists of most countries as a model farming system for full utilization of local resources, for waste recycling and energy saving, and for maintaining ecological balance and circulation. Besides increasing the supply of fish, meat and eggs, and employment opportunities, it also reduces the cost of fish production through utilization of local farm products as fish feeds and fertilizers and reorganization of farm labour for effective output (De Silva 1991).

The Asian-Pacific Regional Research and Training Centre for Integrated Fish Farming (RLCC) in Wuxi, China was created to extend the high-yielding, traditional, integrated fish farming technology to other developing countries. Although this technology is highly productive in certain regions in China and parts of Asia, Sharma (1981) reported that it is now recognized that large-scale technology transfer to most other regions, both inside and outside China, is dependent on a clearer scientific understanding of the physical, chemical and biological processes involved.

1.2 Objectives of the Research

The main goal of this project is to promote a new, environmentally sound, aquaculture industry. The specific objectives are to

- i design, construct and test an integrated poultry/fish housing unit that will promote productive poultry and fish farming in the study area and

- ii develop a model of effect of environmental parameters affecting integrated poultry and fishery husbandry.

1.3 Justification for the Study

In developing countries like Nigeria, many are not informed about integrated fish farming and its attendant benefits. There is virtually no reliable data concerning the feasibility and adoption of the system. Adesulu (2001) stated that integrated fish farming is not a common practice in Nigeria. Fish consumption is meant to play an important role in human nutrition but it is becoming a luxury food in the country. Utilisation of grain and animal protein as feed for aquaculture may not be economical as it might reduce the food availability for human consumption. There is need to be a party to solving the problem of food crises in our nation. This study therefore will provide a suitable platform for the practice of integrated aquaculture in the study area and Nigeria as a whole.

1.4 Research Hypothesis

The research will test the hypothesis that poultry droppings can be fed to fish and the growth of birds in an integrated aquaculture environment can be predicted and modelled

CHAPTER TWO

2 LITERATURE REVIEW

2.1 General

The socioeconomic development of nearly all African nations depends largely on agriculture and animal husbandry which presume, can be best practised by integrated farming systems. Latif *et al.* (1993) defined integrated farming as the association of two or more normally separate farming systems which become part of the whole farming system. The major features of this system include: Recycling of waste or by-product in which the waste of one system becomes the input of other system and efficient utilisation of farm space for multiple productions.

Mahmud *et al.* (1993) noted that integrated livestock-fish, poultry-fish, and rice-fish farming and crop rotation in fish ponds have been well developed and practised in countries like China, Hungary, Germany and Malaysia. Indian freshwater aquaculture has been largely organic-based, with inputs derived from activities of agriculture and animal husbandry with plants and animal residues forming the major components of feeds and fertilizers in carp polyculture. For centuries, small-scale farmers have sustained themselves by practising different kinds of crop diversification. About 80% of India's population live in rural areas at subsistence or near subsistence level. These rural folks are greatly under-nourished and need not only a large supplement of animal protein in their diet but also new sources of gainful employment. Hussain, (1995), observed that India being an agrarian economy produces large quantities of plant and animal residues, the former to the tune of 321.4 million metric tonnes and the latter amounting to about 1000 million metric tonnes of animal dung on annual basis. Hussain, (1995), also noted that the country supports the largest bovine population of over 240 million cattle heads along with 108 million sheep and goats, 7 million pigs, 140 million poultry and other live stock. Activities like mushroom cultivation and rabbitry, silviculture, apiculture,

etc. apart from providing for diversification of farming systems, also provide huge quantities of organic material that may become resources in the aquaculture system.

The agro-based industries like distilleries and food processing plants also produce the effluent that could be recycled to aquaculture apart from the well known resource-domestic sewage to the extent of 4000 million litres per day

2.2 Integrated Poultry/Fish Culture

Literature regarding chicken/fish integration generally relates to battery or deep litter form of production. The birds are typically fed on complete diets in pelleted or mash form and the manure is used as feed (Little and Muir, 1987). The concentrated nutrient content of chicken manure favours its use as an agricultural fertilizer and animal feed supplement in many countries and its high value may therefore prelude its use in integrated aquaculture (Godward, 1981).

Different methods and material are used in the integration. There are broiler-raising systems in South East Asia that use stilted bamboo-type sheds directly over the pond. Typical battery cages may be used for egg layers and broilers, although density of 11 birds/m² is used for growing broilers in the Philippines (Hopkins and Cruz, 1982). In Indonesia, the chickens are kept in battery houses erected on elevated land or the fishpond bank.

Various Chinese integrated fish farming models have evolved according to geography and climate, local agricultural characteristic, socio-economic conditions and traditional practices. For instance one type of integrated fish farm may raise Huzhon sheep which provide manure for growing mulberry on which silkworm live; silkworm dregs are in turn used to feed fish, while the autumn leaves of the mulberry tree are fed to sheep in winter (IDRC, 1998).

In a three-month experimental period, Hopkins and Cruz (1982) have illustrated an increasing fish production with numbers of chicken stocked of up to 5000 broilers/ha of

fishpond. A polyculture of the Nile tilapia, common carp and snake heads were used. Carp yields were highest at approximately half the chicken waste loading for the Nile tilapia.

2.3 Conditions for Fish Culture

Fish culture is usually practised in ponds, excavated bodies of water, which can be filled and drained according to management requirements (Gietema, 1992). A proper range of many environmental factors is necessary for fish culture. The most important factors affecting the growth and survival of fish include the availability of food organisms and the influence of naturally occurring substances such as Dissolved Oxygen (DO), Carbon dioxide (CO₂), ammonia (NH₃), Hydrogen sulphide (H₂S) and Hydrogen ions (H⁺). The quantity of nutrients in solution in the water varies considerably and determines the very different natural productivities, which in turn depend on the physiochemical characteristics (Onuoha and Nwadike, 1989). The role of temperature and salinity requirements, various pollutants may also be of concern in fish culture. Thus the water used for cultivation of fish will not give maximum production if the conditions are not optimal for the fish and other aquatic organisms. Most fishes are still culture in single ponds with limited water exchange (Little and Muir, 1987). They equally observed that the limited water exchange allows a build-up of the nutrients supporting the growth of natural feeds, especially if fertilizers, manure or other waste products are added. For fish culture to thrive well, the following factors are most necessary;

2.3.1 Topography

For maximum efficiency and high production, ponds should preferably be able to be drained. Gietema, (1992) stated that the most economical method is filling and drainage using gravity and gently sloping ground with easy access to the water source (river, spring) is suitable for fishpond construction. He reported that land with a slope of more than 5% is considered less suitable for pond construction because the preparation and maintenance costs of the pond are relatively high.

When gravity can be used, a water canal should be constructed to bring the water from an upstream source to the ponds. When the midfield of the pond is slightly sloping towards the outlet, an outlet canal can be constructed to carry the water from the pond back to the original water stream. Such ponds can be drained without pumps and the out flowing water will not cause erosion of the pond bottom. Pond bottom should be constructed at least 50m above the highest water level.

2.3.2 Soil

The most obvious function of the pond soil is that it holds water, Soil quality is an important factor in fishpond productivity as it controls pond bottom stability, pH and salinity. This means that pond soil can regulate the quality of the overlaying water. Moderately heavy textured soils because of their surface area and high surface charge density, possesses the above characteristics. Too heavy textured soil such as pure clay is not satisfactory, as they have very high adsorptive property and thereby acts as a sink for nutrient, which may not be released to the overlaying water. In general moderately heavy textured soils having neutral pH moderate organic matter content and low salinity levels are desirable for fishponds (Dublin-Green, 1989).

The rearing of fish in ponds has the advantage that most non-arable soils can be utilized. Soils, which are unsuitable, can sometimes be corrected for fish farming and this applies to soil texture in particular. Soils composed purely of coarse sand and grit cannot retain water very well, the particles are too big and water seepage is high. Ferric soils are not suitable for fish culture either; rusty particle will often become attached to the fish gills and hamper respiration. Also the eggshell will become covered by ferric sediments and the eggs will die from lack of oxygen.

The soil can be checked by taking some wet soil in the hand and making a ball. If the ball maintains its form while being played with, the soil is adherent enough and will show little

seepage (Gietema, 1992). Laterite and acid soils are quite common in the tropics and are less suitable for fish culture unless the acidity is neutralized by lime. Application of quicklime or limestone is rather costly. If no other soil types are available the best way to improve the quality of the soil is to mix and plough the soil with lime, green manures and sand to a rather deep level for several months until the pH reaches about 7.

2.3.3 Importance of Water Quality in Aquaculture

Fish perform all their bodily functions in water. Because fish are totally dependent upon water to breathe, feed and grow, excrete wastes, maintain a salt balance, and reproduce, understanding the physical and chemical qualities of water is critical to successful aquaculture (Benefield et al, 1982). To a great extent water determines the success or failure of an aquaculture operation.

2.3.3.1 Water Balance in Fish

The elimination of most nitrogen waste products in land animals is performed through the kidneys. In contrast, Boyd (1979), observed that fish rely heavily on their gills for this function, excreting primarily ammonia. The gills of a fish are permeable to water and salts. In the ocean the salinity of water is more concentrated than that of the fish's body fluids. In this environment water is drawn out, but salts tend to diffuse inward. Hence, marine fishes drink large amounts of sea water and excrete small amounts of highly salt-concentrated urine.

Stickney (1979), stated that in fresh-water fish, water regulation is the reverse of marine species. Salt is constantly being lost through the gills, and large amounts of water enter through the skin and gills of a fish. This is because the salt concentration in a fish (approximately 0.5 percent) is higher than the salt concentration of the water in which it lives. Because the body of a fish is constantly struggling to prevent the "diffusion" of water into its body, large amounts of water are excreted by the kidneys. As a result, the salt concentration of the urine is very low.

By understanding the need to maintain a water balance in freshwater fish, one can understand why using salt during transport is beneficial to fish.

2.3.3.2 Sources and Quality of Water

Water is always a limiting factor in commercial fish production. Many of the negative chemical and environmental factors associated with most operations have their origins in the source of water selected. Final site selection has to be made based on both the quality and quantity of water available. The most common sources of water used for aquaculture are wells, springs, rivers and lakes, groundwater, and municipal water. Of these sources, Reid, George et al (1976), stated that wells and springs are considered to consistently be of high quality.

The availability of good quality water is essential for all fish farming systems but its adequacy (quantity) is of even greater importance for land based fish farming to cater for their needs such as breeding, eating, reproduction and growing (Assiah et al, 1996). FAO (1996) reported that pond water contains two major groups of substances, which include dissolved substances made of gas and organic compound, and suspended particles of every small plants and animals (the planktons and some non living particles).

Water for the pond can be obtained from various sources. Spring water has the best quality, being free from disease organisms, parasites, predator and pesticides. Ground water is less suitable for direct use in a pond. Most times the temperature is too low. It often has high carbon dioxide levels and less oxygen than is required. For these reasons ground water should be exposed to air for a considerable time in order to improve the quality (Gietema, 1992). He also reported that from the point of view of nutrients run-off water is the richest as it takes along nutrients and organic matter from the catchment areas. River water and water from irrigation canals can also be used. Rivers, which have passed several villages usually, contain a good amount of organic waste. Besides the fertility of the incoming water, the water quality in

a pond is determined by factors like temperature, dissolved oxygen (DO), pH, turbidity, minerals and the biological oxygen demand (BOD).

2.3.3.3 Temperature

After oxygen, water temperature may be the single most important factor affecting the welfare of fish. Fish are cold-blooded animals and assume approximately the same temperature as their surroundings. The temperature of the water affects the activity, behaviour, feeding, growth, and reproduction of all fishes. Metabolic rates in fish double for each -8°C rise in temperature.

Fish are generally categorized into warmwater ($23.9\text{-}32.2^{\circ}\text{C}$), coolwater ($18.3\text{-}23.9^{\circ}\text{C}$), and coldwater ($12.8\text{-}18.3^{\circ}\text{C}$) species based on optimal growth temperatures. Channel catfish and tilapia are examples of warmwater species. Their temperature range for growth ranges between $23.9 - 32.2^{\circ}\text{C}$. A temperature of 29.4°C for catfish and 30.6°C for tilapia is considered optimum. Walleye and Yellow perch are examples of coolwater species. Ranges for optimum growth fall between 15.6° and 29.4°C . Temperatures in the upper end of this range are considered best for maximum growth for most coolwater species (Dupree, and Jay 1984). Coldwater species include all species of salmon and trout. The most commonly cultured coldwater species in the Midwest is rainbow trout, whose optimal temperature range for growth is $9\text{-}18.3^{\circ}\text{C}$ (Lagler et al., 1977). Ideally, species selection should be based in part on the temperature of the water supply. Any attempt to match a fish with less than ideal temperatures will involve energy expenditures for heating or cooling. This added expense will subsequently increase production costs (Lagler et al., 1977). Temperature also determines the amount of dissolved gases (oxygen, carbon dioxide, nitrogen, etc.) in the water. The cooler the water the more soluble the gas (Swann, 1990.) Temperature plays a major role in the physical process called thermal stratification. Water has its maximum density at 4°C . In spring, water temperatures are nearly equal at all pond depths. As a result, nutrients, dissolved gases, and

fish wastes are evenly mixed throughout the pond (Swann, 1990, Rottmann and Shireman.2000)

As the days become warmer, the surface water becomes warmer and lighter while the cooler-denser water forms a layer underneath. Circulation of the colder bottom water is prevented because of the different densities between the two layers of water. Lewis et al. (1981b) observed that dissolved oxygen levels decrease in the bottom layer since photosynthesis and contact with the air is reduced. He concluded that the already low oxygen levels are further reduced through decomposition of waste products, which settle to the pond bottom. Localized dissolved oxygen depletion poses a very real problem to the fish farmer. Water used for the cultivation of fish will not give maximum production if the conditions are not optimal for the fish and other aquatic organisms. Temperature has a considerable influence on the principal and vital activities of the fish notably their breathings, growth and production. This is because the body temperature of the fish varies with and is almost the same as that of the environment (Onuoha and Nwadukwe (1989), Rottmann and Shireman (2000)). In tropical countries the temperature is relatively high and fairly stable, enabling the productivity of fishponds to exceed that of ponds in the temperate zones. The temperature of the pond water is determined by the climate and by the volume of the pond (Onuoha and Nwadukwe (1989); Rottmann and Shireman (2000)). The sun's rays can only penetrate the water to a certain degree. In stagnant water the temperature in the upper layer is noticeably higher than in the lower layers. Wind causes a certain degree of mixing.

Cold-blooded animals like fishers are very sensitive to temperature. As the body temperature of a fish varies with and is almost the same as that of its environment, each fish species has a temperature-tolerance range. Within this range each species has an optimal-growth temperature range (Gietema (1992), Onuoha and Nwadukwe (1989), Rottmann and

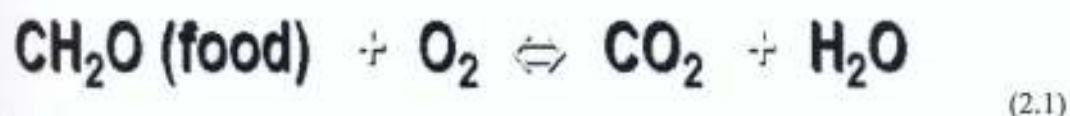
Shireman (2000)). This is the temperature, which suits its metabolism best. Optimal metabolism means good food conversion and optimal growth conditions for production.

Fish only spawn when the temperature of the water is suitable; for instance, tilapia does not reproduce at temperature below 21°C. The optimal growth temperature can be different from the optimal reproduction temperature. The metabolism and activities of the fish will slow down when the temperature drops below its optimal range. Cold-water fish requires 15°C water temperature for breeding and temperature less than 18°C for growth. While warm water fish needs temperature above 15°C to breed and grow best at temperature over 20°C (FAO, 1996).

2.40 Water's Chemico-physical Factors

2.4.1 Photosynthesis

Photosynthesis is one of the most important biological activities in standing pond aquaculture. Many water quality parameters such as dissolved oxygen, carbon dioxide, pH cycles, and nitrogenous waste products are regulated by the photosynthetic reaction in phytoplankton. Simply stated, photosynthesis is the process by which phytoplankton uses sunlight to convert carbon dioxide into a food source and to release oxygen as a by-product as shown in equation 2.1



In addition to supplying oxygen in fish ponds, photosynthesis also removes several forms of nitrogenous wastes, such as ammonia, nitrates, and urea (Rottmann and Shireman, 2000). The phytoplanktonic plant pigments involved in this chemical reaction are referred to as chlorophyll. These are the same pigments found in higher plants such as tree leaves. Because the photosynthetic process is driven by sunlight, greatest concentrations of oxygen occur when the sun is highest on the horizon (usually 2-3 p.m. in the afternoon). At night, photosynthesis

ceases and the phytoplankton primarily respire. Respiration is the reverse of photosynthesis in that oxygen is used by phytoplankton to convert food to energy and carbon dioxide is released as a by-product. Phytoplankton respiration also occurs during the day but fortunately for the fish farmer, there is usually a surplus of oxygen produced to compensate for the loss due to respiration. An exception is during extended periods of cloud cover, Respiration occurring in the absence of photosynthesis causes oxygen levels to decrease throughout the night. As a result the lowest concentrations of oxygen are observed immediately prior to sunrise (Lagler et al. (1977)); Dupree and Jay (1984); Lewis et al (1981b); Meade (1974); and Reid and Richard (1976)).

2.4.2 Dissolved Gases

Dissolved gases are those which are in a water solution. An example of gas dissolved in solution is soda water which has large quantities of dissolved carbon dioxide. The most common gases are oxygen, carbon dioxide, nitrogen, and ammonia. Concentrations are measured in parts per million (ppm) or milligrams per liter (mg/l), both units of measure are the same (Swann (1990); Stickney (1979); Rottmann and Shireman (2000); Brown and Gratzek (1983); Boyd (1979) and Benefield et al. (1982)).

2.4.3 Oxygen

Dissolved oxygen (DO) is by far the most important chemical parameter in aquaculture. Low-dissolved oxygen levels are responsible more for the killing of fish either directly or indirectly, than all other problems combined. Like humans, fish require oxygen for respiration. The amount of oxygen consumed by the fish is a function of its size, feeding rate, activity level, and temperature. Small fish consume more oxygen than do large fish because of their higher metabolic rate. Meade (1974) determined that the oxygen consumption of salmon reared at 14°C was 0.002 pounds per pound of fish per day. Lewis et al. (1981) determined that striped bass raised at 25°C consumed 5.4 g – 9 g (0.012-0.020 pounds) per 0.45 kg of fish per

day. The higher oxygen requirement by striped bass may be attributed to the statement that the metabolic rate doubles for each -8°C increase in temperature. The amount of oxygen that can be dissolved in water decreases at higher temperatures and decreases with increases in altitudes and salinities (Swann (1990); Stickney (1979); Rottmann and Shireman (2000); Brown and Gratzek (1983); and Boyd (1979)).

At sea level and zero salinity 20°C water can hold 9.2 ppm, while at 30°C , saturation is at 7.6 ppm as shown in Table 2.1. In combining this relationship of decreased solubility with increasing temperatures, it can be seen why oxygen depletion are so common in the summer when higher water temperatures occur.

Fish farmer, in an attempt to maximize production, stock greater amounts of fish in a given body of water than found in nature. At times during summer it may be necessary to supply supplemental aeration to maintain adequate levels of dissolved oxygen. Whereas in recirculation systems the farmer must supply 100 percent of the oxygen needed for the fish and beneficial nitrifying bacteria (Swann (1990); Stickney (1979); Rottmann and Shireman (2000); Brown and Gratzek (1983), and Boyd (1979)).

To obtain good growth of fish, Swann (1990); Rottmann and Shireman (2000) stated that fish must be cultured at optimum levels of dissolved oxygen. A good rule of thumb is to maintain DO levels at saturation or at least 5 ppm (Fig. 2.1). Dissolved oxygen levels less than 5ppm can place undue stress on the fish, and levels less than 2 ppm will result in death (possibly 3 ppm for hybrid striped bass and yellow perch). Some warmwater species such as tilapia and carp are better adapted to withstand occasional low DO levels, while most coolwater species cannot.

Fish are not the only consumers of oxygen in aquaculture systems; bacteria, phytoplankton, and zooplankton consume large quantities of oxygen as well. Decomposition of organic materials (algae, bacteria, and fish wastes) is the single greatest consumer of oxygen in aquaculture systems. Problems encountered from water recirculating systems usually stem

from excessive ammonia production in fish wastes. Consumption of oxygen by nitrifying bacteria that break down toxic ammonia to non-toxic forms depends on the amount of ammonia entering the system. Meade (1974) determined that 1.8 – 2.7 kg of oxygen is needed to oxidize 0.45 Kg of ammonia. However, since other bacteria are present in pond and tank culture, a ratio of 2.7 kg of oxygen to 0.45 kg of ammonia is recommended.

Oxygen enters the water primarily through direct diffusion at the air-water interface and through plant photosynthesis. Direct diffusion is relatively insignificant unless there is considerable wind and wave action. Several forms of mechanical aeration are available to the fish farmer. Mechanical aeration can also increase dissolved oxygen levels. Because of the lack of photosynthesis in indoor water recirculating systems, mechanical means of aeration is the only alternative for supplying oxygen to animals cultured in these systems. Oxygen depletions can be calculated, but predictions can be misleading and should never be substituted for actual measurements.

Table 2.1.: Solubility of oxygen (ppm) in water at various water temperatures, salinities, and altitudes.

Variable	Temperature (°C)				
	20.0	22.0	26.0	28.0	30.0
Salinity (ppm)					
0	9.2	8.8	8.2	7.9	7.6
5,000	8.7	8.4	7.8	7.5	7.3
10,000	8.3	8.0	7.4	7.1	6.9
Altitude					
0 (Sea Level)	9.2	8.8	8.2	7.9	7.6
304.80 m or 1,000 ft	8.8	8.5	7.9	7.6	7.4
609.60 m or 2,000 ft	78.5	8.2	7.6	7.3	7.1



Fig. 2.1: General dissolved oxygen requirements in parts per million (ppm) for fish.

2.4.4 Carbon Dioxide

Carbon dioxide (CO_2) is commonly found in water from photosynthesis or water sources originating from limestone bearing rock. Fish can tolerate concentrations of 10 ppm provided dissolved oxygen concentrations are high. Water supporting good fish populations normally contain less than 5 ppm of free carbon dioxide. In water used for intensive pond fish culture, carbon dioxide levels may fluctuate from 0 ppm in the afternoon to 5-15 ppm at daybreak. While in recirculating systems carbon dioxide levels may regularly exceed 20 ppm. Excessively high levels of carbon dioxide (greater than 20 ppm) may interfere with the oxygen utilization by the fish (Swann (1990); Rottmann and Shireman (2000); Brown and Gratzek (1983) and Boyd (1979)).

Rottmann and Shireman (2000) stated that there are two common ways to remove free carbon dioxide. First, with well or spring water from limestone bearing rocks, aeration can "blow" off the excess gas. The second option is to add some type of carbonate buffering material such as calcium carbonate (CaCO_3) or sodium bicarbonate (Na_2CO_3). Such additions will initially remove all free carbon dioxide and store it in reserve as bicarbonate and carbonate buffers.

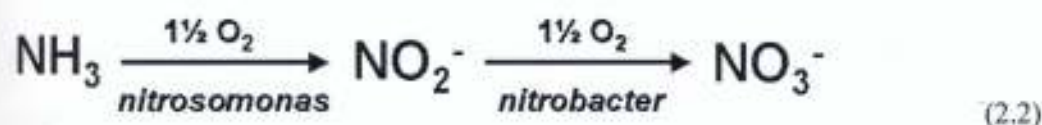
2.4.5 Nitrogen

Dissolved gases, especially nitrogen, are usually measured in terms of "percent saturation." Any value greater than the amount of gas the water normally holds at a given temperature constitutes supersaturation. A gas supersaturation level above 110% is usually considered problematic (Swann (1990); Stickney (1979); Rottmann and Shireman (2000); Brown and Gratzek (1983)). Gas bubble disease is a symptom of gas supersaturation (Rottmann and Shireman (2000)). The signs of gas bubble disease can vary. Bubbles may reach the heart or brain, and fish die without any visible external signs. Other symptoms may be bubbles just under the surface of the skin, in the eyes, or between the fin rays. Rottmann and

Shireman (2000) concluded that the treatment of gas bubble disease involves sufficient aeration to decrease the gas concentration to saturation or below.

2.4.6 Ammonia

Fish excrete ammonia and lesser amounts of urea into the water as wastes. Two forms of ammonia occur in aquaculture systems, ionized and un-ionized. Percentage of total ammonia that is un-ionized at various temperatures and pH is shown in Table 2.2. The un-ionized form of ammonia (NH_3) is extremely toxic while the ionized form (NH_4^+) is not. Both forms are grouped together as "total ammonia." Through biological processes, toxic ammonia can be degraded to harmless nitrates according to equation 2.2, (Lagler et al (1977); Dupree and Jay (1984); Lewis et al. (1981b); Meade (1974) and Reid and Richard (1976)).



Dupree and Jay (1984) observed that in natural waters, such as lakes, ammonia may never reach dangerous high levels because of the low densities of fish, but the fish farmer must maintain high densities of fish and, therefore, runs the risk of ammonia toxicity. Un-ionized ammonia levels rise as temperature and pH increase as shown in Table 2.3. To determine un-ionized ammonia concentration, multiply total ammonia concentration by the percentage which is closest to the observed temperature and pH of the water sample. For example, a total ammonia concentration of 5 ppm at pH 9 and 20 °C would be: 5 ppm total ammonia X 28.5% = 1.43 ppm.

Toxicity levels for un-ionized ammonia depend on the individual species; however, levels below 0.02 ppm are considered safe. Dangerously high ammonia concentrations are usually limited to water recirculation system or hauling tanks where water is continually recycled and in pond culture after phytoplankton die-offs. However, the intermediate form of ammonia--

nitrite--has been known to occur at toxic levels (brown-blood disease) in fish ponds (Swann (1990); Stickney (1979); Rottmann and Shireman (2000); Brown and Gratzek (1983); Boyd (1979) and Benefield et al. (1982)).

2.4.7 Buffering Systems

A buffering system to avoid wide swings in pH is essential in aquaculture. Without some means of storing carbon dioxide released from plant and animal respiration, pH levels may fluctuate in ponds from approximately 4-5 to over 10 during the day. In recirculating systems constant fish respiration can raise carbon dioxide levels high enough to interfere with oxygen intake by fish, in addition to lowering the pH of the water.

2.4.8 pH

pH is a symbol expressing the acidity of water. The water is considered neutral if the pH value is around 7. Higher than 7 means that the water is alkaline (OH), a pH lower than 7 means that the water is acid (H⁺). The pH can be checked by using litmus paper. This is special kind of paper (pH indicator paper), which turns red in acid water and blue in alkaline water. The quantity of hydrogen ions (H⁺) in water will determine if it is acidic or basic. The scale for measuring the degree of acidity is called the pH scale, which ranges from 1 to 14. The acceptable range for fish culture is normally between pH 6.5-9.0 (Swann (1990)). Onuoha and Nwadukwe (1989) reported that fish grow best between pH 6.5 and 9 and would prefer slightly alkaline water close to neutral pH. Deviation from the optimum range impedes the circulation of nutrient by reducing the rate of decomposition of organic matter and inhibits nitrogen fixation. Therefore low pH (means acid water) has a negative effect on the organisms forming the food of the fish and ultimately on the growth of the fish itself. A high pH (alkaline water) can impede the growth of zooplankton.

Table 2.2: Percentage of total ammonia that is un-ionized at various temperatures and pH.

pH	Temperature					
	12.2°C	16.7°C	20.0°C	23.9°C	27.8°C	32.2°C
7.0	0.2	0.3	0.4	0.5	0.7	1.0
7.4	0.5	0.7	1.0	1.3	1.7	2.4
7.8	1.4	1.8	2.5	3.2	4.2	5.7
8.2	3.3	4.5	5.9	7.7	11.0	13.2
8.6	7.9	10.6	13.7	17.3	21.8	27.7
9.0	17.8	22.9	28.5	34.4	41.2	49.0
9.2	35.2	42.7	50.0	56.9	63.8	70.8
9.6	57.7	65.2	71.5	76.8	81.6	85.9
10.0	68.4	74.8	79.9	84.0	87.5	90.6

2.4.9 Alkalinity

Alkalinity is the capacity of water to neutralize acids without an increase in pH. This parameter is a measure of the bases, bicarbonates (HCO_3^-), carbonates (CO_3^{--}) and, in rare instances, hydroxide (OH^-). Total alkalinity is the sum of the carbonate and bicarbonate alkalinities. Some water may contain only bicarbonate alkalinity and no carbonate alkalinity.

The carbonate buffering system is important to the fish farmer regardless of the production method used. In pond production, where photosynthesis is the primary natural source of oxygen, carbonates and bicarbonates are storage area for surplus carbon dioxide. By storing carbon dioxide in the buffering system, it is never a limiting factor that could reduce photosynthesis, and in turn, reduce oxygen production. Also, by storing carbon dioxide, the buffering system prevents wide daily pH fluctuations.

Without a buffering system, free carbon dioxide will form large amounts of a weak acid (carbonic acid) that may potentially decrease the night-time pH level to 4.5. During peak periods of photosynthesis, most of the free carbon dioxide will be consumed by the phytoplankton and, as a result, drive the pH levels above 10. Fish grows within a narrow range of pH values and either of the above extremes will be lethal to them. In recirculating systems where photosynthesis is practically non-existent, a good buffering capacity can prevent excessive buildups of carbon dioxide and lethal decreases in pH. It is recommended that the fish farmer maintain total alkalinity values of at least 20 ppm for catfish production. Higher alkalinities of at least 80-100 ppm are suggested for hybrid striped bass. For water supplies that have naturally low alkalinities, agriculture lime can be added to increase the buffering capacity of the water (Swann, 1990, Stickney 1979, Rottmann and Shireman 2000, Brown and Gratzek 1983, Boyd 1979, and Benefield et al 1982.)

2.4.10 Hardness

Water hardness is similar to alkalinity but represents different measurements. Hardness is mainly a measure of Ca and Mg, but other ions such as Al, Fe, Mn, St, Zn, and hydrogen ions are also included. When the hardness level is equal to the combined carbonate and bicarbonate alkalinity, it is referred to as carbonate hardness. Hardness values greater than the sum of the carbonate and bicarbonate alkalinity are referred to as non-carbonated hardness. Hardness values of at least 20 ppm should be maintained for optimum growth of aquatic organisms. Low- hardness levels can be increased with the addition of ground agriculture lime (Swann, 1990); Stickney, 1979); Rottmann and Shireman, 2000)).

2.4.11 Other Metals and Gases

Rottmann and Shireman (2000) reported that other metals such as iron and sodium, and gases, such as hydrogen sulphide, may sometimes present special problems to the fish farmer and water-quality criteria for aquaculture hatcheries or production facilities as shown in Table 2.3. Most complications arising from these can be prevented by properly pre-treating the water prior to adding it to ponds or tanks. The range of treatments may be as simple as aeration, which removes hydrogen sulphide gas, to the expensive use of iron removal units. Normally iron will precipitate out of solution upon exposure to adequate concentrations of oxygen at a pH above 7.0.

2.4.12 Turbidity

Turbidity refers to the decreased ability of water to transmit light caused by suspended particular matter ranging in size from colloidal coarse dispersions (Onuoha and Nwadukwe, 1989). Turbidity depends on the amount of solid particles suspended in the water. The more muddy the water, the less chance that light can penetrate very deeply. The incoming light is the determining factor for the production of phytoplankton, so directly the silt particles can reduce the natural food supply in the pond. During the rainy season there is a good chance

that turbid water will enter the pond and damage the gill system of the fishes. It also clogs the filter feeding and digestive organs of some zooplankton. In ponds, turbidity and colour may result from colloidal clay particles entering with runoff, colloidal organic matter originating from the decay of vegetation or from abundance of plankton. For example, ponds used for intensive fish culture are normally loaded with plankton (Onuoha and Nwadukwe, (1989). Most clay turbidity problems are the result of exposed soil on the pond level, exposed watershed, crayfish activity, or feeding of bottom dwelling species such as carp and catfish. Turbidity levels exceeding 20,000 ppm can cause behavioural changes in fish. In natural bodies of water, turbidity values seldom exceed these critical levels. Even "muddy looking" ponds rarely have concentrations greater than 2,000 ppm.

Turbidity caused by clay or soil particles, however, can restrict light penetration and limit photosynthesis. Sedimentation of soil particles may also smother fish eggs and destroy beneficial communities of bottom organisms such as bacteria.

Removal of clay turbidity can be accomplished by adding materials that attach to the negative charges of the clay particles, forming particles heavy enough to settle to the bottom. Common remedies for clay turbidity are 7-10 square bales of hay per surface acre, or 300-500 pounds of gypsum per surface acre. Gypsum applications may be repeated at two week intervals if ponds do not clear.

2.4.13 Suspended Solids

Suspended solids is a term usually associated with plankton, fish wastes, uneaten fish feeds, or clay particles suspended in the water. Suspended solids are large particles which usually settle out of standing water through time. Large clay particles are an exception. Clay particles are kept in suspension because of the negative electrical charges associated with them.

2.4.14 Plankton

Turbidity caused by phytoplankton (microscopic plants) and zooplankton (microscopic animals) is not directly harmful to fish. Phytoplankton (green algae) not only produces oxygen, but also provides a food source for zooplankton and filter feeding fish/shellfish. Phytoplankton also uses ammonia produced by fish as a nutrient source. Zooplankton is a very important food source for fry and fingerlings such as hybrid striped bass and yellow perch. However, excessive amounts of algae can lead to increased rates of respiration during the night thereby consuming extra oxygen. Excessive phytoplankton buildups or "blooms" which subsequently die will also consume extra oxygen. Any wide swings between day and night oxygen levels can lead to dangerously low oxygen concentrations (Swann, (1990) and Stickney (1979)).

TABLE 2.3: Suggested water-quality criteria for aquaculture hatcheries or production facilities.

Chemical	Upper Limits for Continuous Exposure and/or Tolerance Ranges
Ammonia (NH ₃)	0.0125 ppm (un-ionized form)
Cadmium ^a	0.004 ppm (soft water < 100 ppm alkalinity)
Cadmium ^b	0.003 ppm (hard water > 100 ppm alkalinity)
Calcium	4.0 to 160 ppm (10.0-160.00 ppm d)
Carbon dioxide	0.0 to 10 ppm (0.0-15.0 ppm d)
Chlorine	0.03 ppm
Copper ^c	0.006 in soft water
Hydrogen sulphide	0.002 ppm (Larsen - 0.0 ppm)
Iron (total)	0.0 to 0.15 ppm (0.0-0.5 ppm d)
Ferrous ion	0.00 ppm
Ferric ion	0.5 ppm (0.0-0.5 ppm d)
Lead	0.03 ppm
Magnesium	(Needed for buffer system)
Manganese	0.0 to 0.01 ppm
Mercury (organic or inorganic)	0.002 ppm maximum, 0.00005 ppm average
Nitrate (NO ₃)	0.0 to 3.0 ppm
Nitrite (NO ₂)	0.1 ppm in soft water, 0.2 ppm in hard water
Nitrite-nitrogen	0.03 and 0.06 ppm nitrite-nitrogen
Nitrogen	Maximum total gas pressure 110% of saturation
Oxygen	5.0 ppm to saturation; 7.0 to saturation for eggs or broodstock
Ozone	0.005 ppm
pH	6.5 to 8.0 (6.6-9.0d)
Phosphorus	0.01 to 3.0 ppm
Polychlorinated biphenyls (PCBs)	0.002
Total suspended and settleable solids	80.0 ppm or less
Total Alkalinity (as CaCO ₃)	10.0 to 400 ppm (50.0-400.0 ppmd)
% as phenolphthalein	0.0 to 25 ppm (0.40 ppmd)
% as methyl orange	75 to 100 ppm (60.0-100.0 ppmd)
% as ppm hydroxide	0.0 ppm
% as ppm carbonate	0.0 to 25 ppm (0.0-40.0 ppmd)
% as ppm bicarbonate	75 to 100 ppm
Total Hardness (as CaCO ₃)	10 to 400 ppm (50.0-400.0 ppmd)
Zinc	0.03-0.05 ppm

(Source: Modification from Wedemeyer, 1977; Piper, *et.al.* (Larsen), 1982)

^aTo protect salmonid eggs and fry. For non-salmonids 0.004 ppm is acceptable

^bTo protect salmonid eggs and fry. For non-salmonids 0.03 ppm is acceptable

^cCopper at 0.005 ppm may suppress gill adenosine triphosphatase and compromise smoltification in anadromous salmonids. d Warm water situations

Suspended fish wastes are a serious concern for water recirculating culture systems. Large amounts of suspended and settleable solids are produced during fish production. As a rule, one pound of fish waste is produced for every pound of fish produced. Fish waste particles can be a major source of poor water quality since they may contain up to 70 percent of the nitrogen load in the system. These wastes not only irritate the fish's gills, but can cause several problems to the biological filter. The particulate waste can clog the biological filter, causing the vitrifying bacteria to die from lack of oxygen. Particulate waste can also promote the growth of bacteria that produces--rather than consumes ammonia.

2.5 Pond Fertilization

Fertilizers are natural or synthetic substances that are used in ponds to increase the production of the natural food organisms to be eaten by fish. These organisms include phytoplankton, zooplankton and insects. They are all part of complex food web used in fish production (FAO, 1996). By increasing the availability of major nutrients, fertilizers promote the development of plankton algae, which provide food for many fish.

Before the pond is filled with water, manure should be spread over the pond bottom in order to increase the natural productivity of the pond. The base manure should preferably be mixed with the pond soil to prolong its fertilizing effect. After this the pond should be filled to a level of about 0.5m only because the higher temperature in shallow water will stimulate the mineralization processes (Gietema, 1992).

In order to maintain the fertility of the pond water additional amounts of manure should be applied to fingerling and production ponds. The quantities should be in line with what one observes to the fertility level of the water. Several small applications are better than our large

application. In addition to only manure (animal dung or green fodder) inorganic fertilizer (chemical) can be used to increase the productivity of the pond.

2.5.1 Fresh Organic Manure

Manure stimulates the natural food production in a pond. High fish yields can be obtained with good management and the manure does not affect the quality of the fish. Fresh animal manure is the richest in nutrient and can be directly applied to the ponds. Ducks and goose-pens, pigsties and poultry coop can be built on the dykes around the ponds or even above the ponds. Wasted feed and manure will then enter the pond directly without the need for transportation.

The number of animals kept should correspond with the size of the pond. Some manure however must be composted to avoid spreading of diseases. When waste material enters a pond system, they may either be consumed directly by the fish or may act indirectly after being broken down the support the pond food web (Little and Muir, 1987). Manuring should preferably take place in the morning, to allow enough time of decomposition and oxygen replacement by photosynthesis. It is best to have fixed manuring sites in the pond so that possible oxygen problems are restricted to one or two places only.

2.5.2 Composition of Animal Manure

The chemical composition of organic manure varies greatly according to the animal from which it originates, namely the specie, age, sex, the nature of its diet and according to the way the manure is handled, relative freshness, condition of storage and rate of dilution with water (FAO, 1996). In some cases, total wastes made of dung and urine are available while in others only solid waste can be collected. Throughout the world, most animal manure is obtained from a limited number of species such as buffalo, cattle, horses or donkeys, sheep, goats, pigs, rabbits and poultry (chicken, ducks, geese).

Chicken manure is very fertile to pond water because of its high nitrogen content. The nitrogen in the chicken manure is mainly in the form of uric acid, which cannot easily be

mineralized. About 70-80% of the nitrogen, 60-80% of the phosphorus and 80-90% of the potassium that is given to the animals in feeds can be recovered in the manure (Gietema, 1992). Waste from poultry has been found to contain the higher concentration of N, P and K followed by those of pigs and then cattle (Little and Muir, 1987). The fibre content of chicken manure pond to be 45%, (10% lignin, 35% crude fibre) and considered to be richer source of carbon.

2.6 Stocking of Fish in Ponds

This means stocking the right type of fish at the right time. The more fish stocked the higher the yield provided there is no competition for food (Moses, 1992). Stocking density can be increased through polyculture, the culture of different species in the same pond at the same time. This method is based on the different food habit of the respective species, which allow the various water layers and all potential food sources to be utilized.

Moses, (1992) informed that in monoculture only one species of fish is stocked in the same pond. The stocking density in this case can be increased through multiple stocking of different age and size groups provided the fish has different food and feeding habits at different stages of its history.

2.7 Breeding of Poultry

2.7.1 Feed Requirement and Composition

It is important to make sure that a chicken gets enough good quality feed. The quality of the feed depends mainly on how concentrated it is and what is made of. The diet of a chicken must include the following elements; energy, protein, minerals, vitamin & water (Agrodoks, 1990). The energy comes mainly from the grain in the feed. Webster and Wilson (1989) reported that the main carbohydrates supplies for pigs and poultry are cereal, grains and by products, cereal contain between 60 and 80- percent of starch, and numerous tropical roots crops such as yams, sweet potatoes, tannias, cassava, feed

elements containing protein also provide energy. Calcium is a particularly important mineral for the layer because it enables them to make strong eggshells. Vitamins are necessary for a good production. A final very important food element is water. There must always be plenty of clean, fresh water for the chicken.

2.7.2 Physical characteristics of food

The factors, which influence food intake, include its physical characteristics such as particle size, colour, taste and small and bird's familiarity with it (Michael et al, 1992). The effect of these features may be described as food's palatability. It is not possible to quantify palatability except by measuring food intake, but some variations in preference cannot be accounted for by any other known factors.

Poultry come to prefer the kind of food to which they are accustomed to and a major change of diet can result in problems unless the new diet is similar in texture, colour & probably taste. One there may follow a reduction in food intake and therefore a check in growth rate under normal conditions the diet is changed at least twice.

2.7.3 Amount of Feed and Feeding Methods for Housed Chicken

As soon as chicken are kept in a poultry house the chicken raiser must give the chicken all the food they need. There are different age categories. In general, there are two kinds of feed for the raising period (the period 0 to 18 weeks in which the chick matures until it can start laying). There are also only one or more kinds of chicken feed for laying hen, but it is possible to use only one kind of good feed (Agrodoks, 1990).

There are two undesirable situations, either the chickens eat too little or they eat too much. If the chicken eat too little, it is good to give extra lights in the morning and the evening. At those times it is cooler and the chickens will be able to eat more, stirring the feed during the

day can also help. A sudden decrease in food intake may be due to a disease outbreak or bad quality.

If chicken eat too much there are again several possible causes. It is possible that some of the feed is spit. It is possible that the quality, in particular the concentration of the feed is low. Chicken kept in a closed chicken house must be given extra grit. This is necessary for the grinding up and digestion of the food. Feed can only be stored for a short time if it is kept long the quality of the feed will decrease.

2.7.4 Drinking Water Requirement of Poultry

Frequency of watering is a factor in assuring proper water intake. Poultry drink small amount at a time (Agrodoks, 1990). Feeds are low in moisture, so birds need a constant supply of water in close proximity to the feed and with the proper allowance of drinking space (Homer and Philip, 1980). He observed that at high very high temperature, chickens need much more water. At temperature of about 20°C, they drink about twice as much water as they eat food as shown in Table 2.4. As it gets warmer chicken eat less and less. The amount of water chickens need depends a lot on the humidity of the air. When it is very humid, the chicken will start to pant (i.e. they start to breath quicker with their mouths open). The water the chicken is given should always be fresh and clean.

2.7.5 Health Care of Poultry

It is very important to keep the chance of infection by contacts with source of infections to a minimum. Germs can be spread via animals and via people (Agrodoks, 1990). Infection is also possible through contact with infected objects such as crate or cars. All kinds of diseases can be transferred by birds, insects and other parasite. Feed and dirty water can also carry germs.

Table 2.4. Temperature/feed water ratio for poultry production

Temperature °C	Ratio feed eaten: water drunk
20	1:2
25	1:2
30	1:4
35	1:6

Source (Agrodoks, 1990)

Feed and water restriction have a fundamental effect on the way broiler breeder respond to certain disease conditions (Mark, 1993).

Many diseases gain entrance into poultry through feed, water, air and litter (Homer and Philip, 1980). It is difficult to disassociate contamination of feed from that of litter, equipment, air and water. Nevertheless where nutrition and sanitation have been controlled as much as possible, results have suggested that there may be some transmission of pathogens by way of the feed under certain circumstances.

Homer and Philip (1980) reported that many diseases are transmitted in batteries and there are typical battery diseases, which are often the result of restricted exercise. While the background of battery fatigue is still unknown, systems occur in birds that have been in production for about 6 to 8 weeks. Micheal et al, (1992) reported that one main advantage of cage is that birds are separated from their faeces. This is important in the control of diseases such as coccidiosis.

Poultry that have been well fed and managed and vaccinated against known local disease usually remain healthy (Payne, 1990). The greatest emphasis should be on disease prevention, but if there is a disease outbreak, the sick should be culled from healthy birds, strict sanitary measures should be applied in all housing and a veterinarian should be immediately notified.

2.8 Hot Weather Management of Poultry

Hot weather can have a severe impact on poultry performance. Production efficiency can be affected long before the temperature reaches a level at which survival becomes a concern. Kenneth and Thomas (1998) stated that heat stress begins when the ambient temperature climbs above 27°C and is readily apparent above 29.4°C. They observed that when a bird begins to pant, physiological changes have already started within its body to dissipate excess heat. Even before the bird reaches this point, anything that can be done to help birds remain comfortable will help maintain optimum growth rates, hatchability, egg size, egg shell quality, and egg production.

2.8.1 Heat stress

Essentially, heat is produced by bodily processes (metabolism) which include maintenance, growth and egg production. Heat production is affected by body weight, species and breed, level of production, level of feed intake, feed quality and, to a lesser extent, by the amount of activity and exercise. If the stocking density is too high for the size and design of house and ventilation equipment, the temperature may rise dangerously since there will be more metabolic heat being added to the house air than was planned for. Radiant transfer from bird to bird is then greater and stagnant hot air is trapped between the birds. Although temperature measured with an ordinary thermometer is the simplest single index of thermal strain on birds, there is much more to it than that. Kenneth and Thomas, 1998 observed that characteristics of the bird which affect heat loss include feather cover and the size of the combs and wattles as shown in Table 2.5. He stated that Posture has considerable influence on heat loss and heat can be lost in a variety of ways which include:

Radiation - losses are proportional to the temperature difference between the body surface and the surrounding surfaces. Thus, hot poorly insulated roofs increase house temperature and make heat stress worse in hot weather in the same way as direct sun on free range birds.

Convection - heat loss will occur from the natural rise of warm air from around a hot body. It can be assisted by providing moving air but only if the air moves fast enough to break down the boundary layer of still air which surrounds the body.

Evaporation - such losses are very important at high temperatures. Poultry do not sweat, but they depend on panting, and this is only effective if the humidity is not too high. Hot humid conditions are therefore much more stressful than hot dry conditions.

Conduction - conduction is relatively unimportant but heat will flow by direct surface to surface transfer if the birds are seated on litter which is cooler than their bodies. However, the litter immediately under the birds soon assumes a temperature close to that of the body.

2.8.2 House Heat Balance

Heat is added to the air of a building by the body heat production, heat from electric lights and motors, sometimes heat from the roof and walls, and heat from fermentation of the litter or accumulated droppings. Of these, Seedorf *et al* (1998) stated that the dominant source of heat is body heat. Fermentation of litter is usually at least equalled by the heat absorbed in evaporating litter moisture. The heat of electric lights and motors is a very small fraction of that produced by the body metabolism (normally less than 1%). However, radiated heat coming from a poorly insulated roof can make heat stress worse in hot weather. Heat is lost via ventilated air and by conduction through the roof and walls when not in direct sunlight. In hot weather, the air change is the dominant route. The body temperature of a bird must remain within narrow limits if its welfare is to be safeguarded and production maintained at acceptable levels. Therefore, there has to be a balance between body heat production and body heat loss. Heat is lost, at a controlled rate, so that body temperature is held constant. The birds are stressed if they have difficulty achieving this balance and die when heat production is substantially greater than heat loss over long periods. The main indicator of heat stress is prolonged panting. If this is not rectified, it will lead to collapse and death of the birds.

2.8.2.1 Physiological Effects of Panting

Pedersen et al, (1998) reported that panting removes heat by the evaporation of water from the moist lining of the respiratory tract. However, panting itself generates body heat, and it causes poultry to eliminate water from the body. It can induce respiratory alkalosis, which occurs because the bird "blows off" excessive carbon dioxide (CO₂) when it pants. As a result, body fluids become more alkaline, causing the kidneys to excrete excessive amounts of several electrolytes (Seedorf *et al*, 1998).

As the shift in body fluid pH occurs, feed intake is increasingly depressed, adversely affecting growth, production, and overall performance of the bird. During the hot summer months, evaporative heat loss typically becomes the primary method by which birds regulate their body temperature unless proper ventilation is provided and other steps are taken to reduce heat stress.

2.8.2.2 Feed and Feeder Management

Any management technique that increases nutrient intake during heat stress will minimize the drop in production efficiency. Three easy ways to increase nutrient consumption are to increase nutrient density, take advantage of natural increases in feed consumption at certain times of the day, and adjust ventilation fans to provide more cooling during the evening. Kenneth and Thomas (1998) reported that a very direct way to ensure optimum nutrient intake despite decreases in feed consumption is to increase the nutrient density of the ration. Recent research indicates that low phosphorus consumption can contribute to increased heat prostration losses.

A second alternative is to feed the birds at the time of day when feed consumption is highest. The light-to-dark cycle results in a U-shaped feed consumption curve. Shortly after light come on, feed consumption is high. It gradually declines during midday and then increases about 1 hour before lights are turned off. If birds are fed during the cool part of the day, feed consumption will be higher. Birds should not be fed during the afternoon in periods

of hot weather since this will increase the amount of body heat that they must dissipate and thus increase the potential for heat prostration. Abrupt changes in feeding times should be avoided.

A third technique is to cool the birds as much as possible during the evening hours. Hens or meat birds tend to build up body heat during extended periods of hot weather. If their body temperature can be reduced during the evening, the birds will be able to consume more feed in the early morning. The house can be cooled in the evening by setting the fan thermostats so that the fans will continue to run until the internal house temperature reaches 24°C (18°C for mature birds).

Table 2.5. Effects of Ambient Temperature on Poultry Production

12.8° to 23.9°C	Thermal neutral zone. The temperature range in which the bird does not need to alter its basic metabolic rate or behavior to maintain its body temperature.
18.3° to 23.9°C	Ideal temperature range.
23.9° to 29.4°C	A slight reduction in feed consumption can be expected, but if nutrient intake is adequate, production efficiency is good. Egg size may be reduced and shell quality may suffer as temperatures reach the top of this range.
29.4° to 32.2°C	Feed consumption falls further. Weight gains are lower. Egg size and shell quality deteriorate. Egg production usually suffers. Cooling procedures should be started before this temperature range is reached.
32.2° to 35.0°C	Feed consumption continues to drop. There is some danger of heat prostration among layers, especially the heavier birds and those in full production. At these temperatures, cooling procedures must be carried out.
35.0° to 37.8°C	Heat prostration is probable. Emergency measures may be needed. Egg production and feed consumption are severely reduced. Water consumption is very high.
Over 37.8°C	Emergency measures are needed to cool birds. Survival is the concern at these temperatures.

Source: *Kenneth and Thomas (1998)*

2.8.3 Prevention of Heat Stress

In a very hot day, solar heat can penetrate a roof if the insulation is deficient. Recent measurements have shown solar gains of up to 30 Watts per square metre (W/m^2) coming through old broiler house roofs, and as much as 85 W/m^2 through single skin roofs. It is important to check the standard of insulation and to bring it up to the modern recommended standard U value of $0.4 \text{ W/m}^2 / ^\circ\text{C}$ or better, as soon as possible. This will also give winter benefits to both welfare and production, due to reduced brooding cost and better air quality at a given temperature by permitting higher ventilation rates. Roof colour, reflectivity, pitch and orientation, and whether the building is in the shade or not is also factors which will have a small bearing on solar heat gain. The choice of insulation material depends upon the type of building structure but, weather material is chosen, it is important to provide a vapour check layer between the insulator and the internal air. Deficiencies in this cheap but important detail have often been the cause of premature deterioration of expensive insulation materials. Some of the modern rigid sheet insulators are supplied with a vapour check layer, or are inherently vapour impervious. This should be checked with the supplier. It is most important that the joints between the sheets are sealed after fitting.

2.8.4 Ventilation and Air Distribution

Kenneth and Thomas (1998) stated that maximum ventilation rates are based on physical calculations of the quantity of air needed to prevent the bird heat, raising house temperature by more than 3°C above outside temperature. Even when there is enough air in the house it is necessary to distribute it uniformly to all of the birds. Modern ventilation systems are designed to achieve this, but unfortunately there are still many inherently poor systems in use. In naturally ventilated houses, the required rate of air change dictates the size of the openings in the walls and roof, and these are calculated according to the height of the building. Thus there is no single rule of thumb for natural ventilation and calculations for each house must be carried out individually. Such calculations may require the services of ADAS or other

ventilation consultants. In power ventilated houses, the maximum ventilation rates recommended dictates the size and number of fans, and have led to simple rules of thumb, such as 1 x 620mm 900 rpm fan per 1,000 laying hens (Seedorf *et al*, 1998). This rule of thumb can also be applied to broilers.

2.8.5 Circulation fans

It is important to distinguish between internal circulation fans, which do not change the air, and the main ventilation fans which do. In hot weather it is often essential to increase the rate of convection loss from the birds by increasing air speed at bird level with extra fans. This technique is particularly useful for broilers on the floor. Recent research suggests an allocation of about 1 circulation fan every 10 to 15 metres along the house, mounted about 2 metres off the floor and aimed slightly downwards. Circulation fans give additional benefits such as getting broilers to stand up and breaking up the layer of stagnant hot air which tends to form around the birds (Seedorf *et al*, 1998). Slow turning ceiling fans were used in early attempts to achieve adequate air mixing but are not now recommended.

It is better to use ordinary propeller fans, mounted for horizontal delivery because they are more effective in increasing the air speed at bird level in hot weather.

2.8.6 Problems with Ventilation Equipment

To avoid serious welfare problems during breakdowns it is essential that ventilation equipment is properly installed and regularly maintained and that alternative ventilation is available in the event of an emergency. Unfortunately there are many installations where the fan performance has been impaired by simple installation errors. For example, the fan box is too small for its fan or the fan box obstructs the air flow in some way. Another common fault is that no bellmouth or diaphragm has been fitted on the fan mounting, or an incorrect mounting ring has been fitted.

2.9 The Fish Pond Environment

Most fish are still cultured in simple ponds with limited, if any, water exchange. The great variety in fish yields reported for such systems (50-13000kg/ha/yr) reflects the wide variation in species employed, local conditions and levels of management. The limited water exchange allows a buildup of the nutrients supporting the growth of natural feeds, especially if fertilizers, manures or other waste products are added. Thus, natural feeds in the pond may reach levels far in excess of those found in most natural aquatic systems. Since the density of fish that can be grown in a volume of water is, within limits, directly related to the abundance of foods, this can improve yields without the use of costly feed inputs. The stimulation of nature feeds can be based on almost any nutrient source, whether used singly or in combination with others. The system is thus extremely flexible and is ideal for accepting the range of raw materials available in integrated farming. The basic principle of pond feeding is that nutrients dissolved in water and sunlight energy are converted into usable cell material for consumption by the fish.

Green, eutrophic, water is typical of fertilized warm water fish ponds. This is often the simplest and most obvious sign that the natural web of food organisms within the pond is productive and that yields of stocked fish will usually be higher than in a natural system. Indeed, such is the quality of this natural feed that fish yields may reach or exceed those possible with conventional fish feeds.

The algae, or phytoplankton, are the primary and most obvious natural food in a fertilized pond. They basically fix nutrients in the water in a form available as food for plankton-eating fish by means of photosynthesis. Production is thus related to both nutrient and sunlight energy input; tropical ponds, receiving high levels of sunlight, have the greatest potential for production of natural feeds. These in turn form the basis of a balance of animal and plant communities, forming a web of feeding relationships. This solar-powered food production is often termed the 'autotrophic' pathway. Phytoplankton are also essential in

producing oxygen in the pond. A second fundamental system, the 'heterotrophic' pathway, is based on the breakdown of dead plant and animal material in the pond by bacteria. Up to certain limits, increases in nutrient input results in an increase in phytoplankton, bacteria and zooplankton production, allowing a consequent increase in organisms feeding on them.

The relative qualities and types of food organism within the pond define the potential for fish yield. Actual yield depends further on the type and numbers of fish stocked, as different species feed on different feed organisms, ranging from phytoplankton to macrophytes, zooplankton, bacteria and detritus. In most cases the basis for fish yield is the light-limited 'autotrophic' phytoplankton production, though in heavily matured ponds the heterotrophic use of wastes by bacteria and protozoa may also be important. In all cases, the primary goal of successful pond operation is the managing of the different pond organisms to maximize the opportunities for fish feeding and growth, and to maximize the absorption of waste materials and their conversion into more useful and stable products.

The term 'sunlit rumen' has been coined (Schroeder, 1978) to describe the warm water manured fish pond and the interaction of processes occurring within it. The maintenance of the 'dynamic balance' of organisms in the pond is usually facilitated by the stocking of a variety of fish species enabling fullest exploitation of the pond's space and its natural diverse food web. In practice, most of the fish stocked should be those capable of feeding low in the food chain on the natural feeds described, rather than predatory or carnivorous fish.

Fish require adequate oxygen as well as food for healthy and sustained growth. If the pond is correctly managed, sufficient oxygen should be available to sustain the metabolic demands of the food web, including the fish. It is essential for the effective management of ponds, and the efficient utilization of the resources within integrated systems, to understand how the food and nutrient cycles of the pond operate and interrelate.

2.9.1 Action of Waste on Fish Pond

When waste materials enter a pond system, they may either be consumed directly by the fish, or may act indirectly after being broken down to support the pond food web. The relative importance of these routes is the subject of some controversy. Present evidence suggests that the value of the manure as direct feed for fish is small compared to its beneficial effect on natural food production within the pond ecosystem.

2.9.2 Wastes as direct feeds

In general, relatively poor responses have been found in growth trials using animal manures as direct feed (Lu and Kevern, 1975). Although some workers e.g Spaturu (1976, 1977) have found little evidence of direct consumption of manures by fish, this undoubtedly does occur in such species as the silver striped catfish *Pangasius sutchi* and the Nile tilapia (*Oreochromis niloticus*). With manures containing large amounts of partially digested feed, direct ingestion of unconsumed elements by the fish may be the most important sources of feeding. Intestinal bacteria are present in all animal manures and these may also attract ingestion by fish. Kerns and Roelofs (1977) found dried poultry waste to be of low nutritional value to fish but considered that the bacteria and protozoa contained in these particles were of high nutritional value to the fish. However, some fish such as the Nile tilapia seem capable of using low quality waste or even non-living detritus as a direct energy source (Edwards, 1982). Recycling of animal wastes to fish and other animals has been the subject of much research, as reviewed by Muller (1982).

2.9.3 Wastes as indirect feeds

Waste could potentially be made available indirectly by either the autotrophic or heterotrophic pathways. The limits to fish production from the autotrophic, plant-based feeding pathway depends largely on the rate of plant production possible within the fish pond, the so called primary production. However, there is no simple relationship.

Nutrient input + solar energy = fish production.

The absorption and use of nutrients, by any species of phytoplankton, is affected by temperature and light intensity. In addition, continual cropping of these algae by planktivorous fish make for a dynamic situation since this removal results in more light and nutrients being made available for the rest of the algae (Reich, 1975). The reduction in 'autoshading' made possible by stocking planktivorous fish has been found to increase production of the algae and the fish, both in terms of pond area and fertilizer used.

The relative merits of organic and inorganic fertilizers and their effectiveness in auto and heterotrophic food chains has caused some controversy (Colman and Edwards, 1985). Organic wastes are undoubtedly valuable sources of nutrients to power 'autotrophic' production and as substrates for the heterotrophic production and as substrates for the heterotrophic community; they contain not only nitrogen, phosphorus and micronutrients, but also large quantities of carbon. Studies have indicated that inorganic fertilizers alone produce lower fish yields (10-15kg/ha/day) than is possible using organic wastes (30kg/ha/day) (Schroeder, 1978). The source of this improved production appears to be mainly from the stimulation of the autotrophic food chain; organic wastes are a more complete source of nutrients for dense blooms of phytoplankton and allow higher productivity than is possible with chemical fertilizers alone. The heterotrophic food chain is also stimulated both from the detritus in the waste and that produced within the pond in the form of dead and dying algae.

2.9.4 The role of fish in integrated systems

The use of fish species feeding low in the food web, such as carps and tilapias, as opposed to carnivorous species, is a general feature of waste-fed culture systems. This allows increased production using only the natural foods produced in the ponds, and/or low grade supplementary feeds. Fish usually eat selectively in response to the range of available feeds, although they may be more flexible in their feeding when farmed. Polyculture, or mixed species culture, takes advantage of this diversity of feeding preference and is often important in allowing higher stocking densities and, hence, yields.

Polyculture of different fish species within the three dimensional pond environment may be compared with multiple cropping of land crops. The polyculture concept may be extended to include an integrated farm as a whole, with animals, plants, and fish all cultured together to optimize output and nutrient utilization. This may be especially important where land is limited, and this approach may be the only practical means for sustainable small-scale agriculture in many parts of the developing world.

2.9.5 Practical considerations. Monoculture/polyculture

Fundamentally, competition between fish species within a polyculture can be avoided if their feeding strategies are not the same. Maximum advantage might therefore be expected in polyculture of the most specialized feeders. For instance, Chinese carp polycultures seem to be more productive than those of the less specialised feeding Indian major carps.

A polyculture using a large number of fish species would be expected to best utilize the diverse environment of the waste-fed pond. In a Chinese carp polyculture, at least four kinds of carp are stocked together in pond systems; a surface feeder, grass carp (*Ctenopharyngodon idella*) that feeds mainly on higher aquatic plants, two pelagic mid water feeders, one of which, the silver carp (*H. molitrix*) prefers phytoplankton for food, and the other; bighead carp (*A. nobilis*), zooplankton.

A further group of bottom feeding omnivores which can be stocked include the common carp (*Cyprinus carpio*), the mud carp (*Cirrhina molitorella*) and bland carp (*Mylopharyngodon piceus*). Whereas traditionally in China at least four or five species were used, it is increasingly common for more to be added in the hope of further increases of yield (FAO, 1983). Elsewhere, however, polycultures often contain fewer fish species than those used in China, where the practice began.

Many polycultures may use only two or three species but still achieve considerable improvements in yield over single species culture. The stocking of common carp, for instance

with one other species, such as silver carp or tilapia has significantly increased yields in Israel (Yashouv, 1971).

The expansion of polyculture in other places may be hampered by several factors. It is crucial to the success of polyculture to stock compatible fish of diverse feeding habits. This requires experience and an understanding of the ecology of local fishes if these are to be used. The use of local fishes may also be problematic if there is a lack of wild fry and/or hatchery technology. For these reasons the wholesale import of tried and trusted forms of polyculture has been attempted, often using the basic Chinese and Indian carps. By contrast, the simplicity of monoculture and the stocking of a single fish species, often of higher individual value, may often be very attractive.

In principle, one species cannot efficiently use all the available food in a waste-fed pond, though stocking omnivorous and less specialized feeding fish is better than using those more selective in their diet. However, some of the highest yields observed in integrated systems have been achieved in monoculture. Yields of the Nile tilapia, *Oreochromis niloticus*, for instance, in waste-fed ponds, suggest such systems are practical. This species is particularly tolerant of poor water quality and thus allows the use of higher waste loads than are possible in polycultures that include more sensitive fish.

Other factors may practically limit polyculture. Hefner and Pruginin (1981) have identified that extra handling at harvest for polyculture compared with monoculture is expensive in terms of manpower and equipment. The different species of fish in a polyculture may also reach marketable size at different times, further complicating harvest procedure. In China, a significant factor in the high production achieved is the ready availability of labour for the complex and labour intensive polyculture strategies employed.

The use of polyculture may therefore be restricted by management considerations. The market value and acceptability of component species within the polyculture may also be a problem. A good example of this is the silver carp which, although commonly included in

polycultures because of its efficient harvesting and use of phytoplankton, generally commands a poor price compared to other, less biologically useful, species.

2.9.6 Developments in polyculture

In spite of these possible drawbacks, progress and development in polyculture systems continue. Recently, more accurate assessments of the nutritional and living requirements of individual species have indicated more clearly the specific advantages of polyculture over monoculture and have identified the best ratios of species for use. The introduction of *Macrobrachium rosenbergii*, the giant freshwater prawn, into Israel, and consequent research into appropriate culture systems, is an excellent example. Originally considered a candidate for intensive pond monoculture (Mires, 1983), recently research suggests that the best overall economic return (though not necessarily the highest production) can be obtained in a polyculture with such finfish as tilapia and common carp. Contributing factors in the improved performance of stocks within the polyculture include reduced competition and cannibalism of the prawns (aided by stocking fewer, larger (rg) juveniles) and improved environmental conditions, associated with the feeding activities of the fish. Cohen and Ra'anani (1983) report that the prawn yields and average weights are independent of hybrid tilapia stocking rates in polycultures. Evidence from studies using different feeding/manuring strategies suggests that *Macrobrachium* prawns within polycultures feed mainly on the natural productivity of the pond which can normally be improved with low cost feed/manuring strategies.

Such findings are important where market demand is changing in favour of prawns, and their production is set to expand. Also, in a polyculture where fish production will provide for local protein consumption (tilapia, carps), *Macrobrachium* will supply external revenue; the use of such low cost inputs yielding a good return with very little commercial risk. The practical management difficulties of a high value prawn/low value tilapia polyculture can be minimized by culturing the fish in cages in the prawn pond. The low value tilapia are thus prevented from eating the costly prawn feed, whilst maintaining water quality by consuming

excess phytoplankton. In addition, problems of excessive reproduction of tilapia and harvesting difficulties are minimized.

2.9.7 Polyculture – rational for use in waste-fed systems

In general, polyculture will be advantageous in integrated waste-fed ponds for several reasons.

(a) *Increased production and profit*

The increased yield from fish ponds that can result from polyculture is subject to economic constraints. Shang (1981) states that polyculture will be viable regardless of yield if stocking a secondary high value species increases the total profit for a given pond area (e.g. stocking prawns in milkfish (*Chanos chanos*) ponds). Polyculture in this case may also reduce the risk of loss inherent in the monoculture of high value, but biologically sensitive, species. However, monoculture of a high value species will only be replaced by polyculture (possibly many less valuable species) if the change does not affect the total profit of the continue production. In the latter case, as the relative yields may not be predictable, the system may not be changed.

(b) *Improvement in pond environment*

Mixed species culture may aid in the maintenance or improvement of water quality within the pond, allowing a higher stocking rate of fish. The blooming or super-abundance of the phytoplankton community in intensively manured systems, can, for stance, cause water quality problems. The stocking of phytoplankton feeders, such as silver carp or some tilapia species e.g. the Nile tilapia, can help in their control. Similarly, the use of macrophyte feeders to control emergent weed growth is well documented. The presence of bottom feeding omnivores e.g. common carp may prevent anaerobic conditions occurring and can accelerate the re-suspension and use of nutrients in the water column. Overstocking of these species may result in turbidity however, with detrimental results on primary production.

(c) *Flexibility in integrated systems*

Polyculture is particularly relevant when integrated into well established agricultural practices. Thus, the ratio of fish species can be manipulated to best utilize the particular waste available. This is illustrated by the pre-eminent use of grass carp (*Ctenopharyngodon idella*) in the Pearl River region of China where fish culture is more extensive and reliant on fodder crops for inputs (Edwards 1982). The Chinese consider the grass carp to be a 'living manuring machine' since its high fibre intake and poorly digested diet result in large amounts of faecal waste being produced in the pond and further entering into the food web to feed other fish.

In contrast, in the region of the lower Yangtse River basin, a greater variety of by-products and manures are available and a more even balance of Chinese carps is stocked to sue the water more efficiently.

(d) Control of fry production

Wild spawning within the pond can seriously depress yields. Tilapia species are notorious for the 'stunting' of stocked fish as their off-spring compete with them for food and space within the pond. Stocking of predatory fish, such as the snakehead, *Channa striata* in small numbers may control excessive reproduction and hence maintain the pond population in balance. In practice this balance may be difficult to achieve. However, the potential for fry control exists in many species. Even the polyculture of the bottom feeding omnivorous common carp with tilapia is reported (Yashouv, 1971) to control the fry production of the latter, although the method is subject to some conjecture.

2.9.8 Waste loading and environmental quality

2.9.8.1 Oxygen

The maintenance of adequate levels of dissolved oxygen is an essential part of achieving high fish production. Anoxia, or oxygen deficiency, has been identified as one of the major causes of fish kills in waste-fed ponds. If the oxygen content of the water in such ponds is analysed throughout a 24 hour cycle, a large variation will be observed. This is

basically because of a change in oxygen production and use (respiration) within the pond. Phytoplankton, by way of photosynthesis during daylight hours, are the main producers of oxygen within the pond. Respiration by the plankton, heterotrophic and fish communities, is the primary consumer of oxygen throughout the cycle. Fertile ponds exhibit large fluctuations in oxygen content, usually reaching a maximum in the late afternoon after daylight photosynthetic production, and a minimum level on the early morning.

Clearly, food and oxygen production within the pond are linked. The correct balance of waste inputs and living communities, phytoplankton or bacteria, is thus important in preventing anoxia, whilst at the same time allowing efficient food production. Over addition of waste inputs for instance, encouraging a super-abundance of phytoplankton and bacteria, can cause a reduction in oxygen production over the daily cycle, and an increase in its consumption compared to less fertile systems. The former occurs because of autoshading which reduces light intensity to algae deeper in the pond and hence overall oxygen production. Thus, the importance of fish grazing on phytoplankton becomes apparent. Recent experimentation using the Nile tilapia has revealed more clearly the interrelationship between phytoplankton and oxygen production in waste-loaded ponds. Colman and Edwards (1985) found that the net production of blue-green algae *Microcystis* was actually stimulated by grazing activity of the fish: since the photosynthetic oxygen production in the pond is proportional to the net production of algae – both feed and oxygen reach a maximum value at the same time. An abundance of dissolved oxygen also stimulates food production by bacteria via the heterotrophic pathways. Conversely, phytoplankton growth can be limited by the availability of nutrients, which are being made available by the activity of the heterotrophs. Thus, it is clear that both major feeding pathways are dynamically linked and essential to the maintenance of water quality.

Climatic conditions are also important factors in preventing anoxia. The prevailing temperature, for instance, affects the dissolved oxygen content. The amount of oxygen in water

decreases as temperature rises; at high temperatures, not only is less oxygen available, but the fishes' metabolism increases and requires more oxygen. Sunlight, its duration and intensity are also important. Cloudy conditions, for instance, reduce light intensity and the lowered photosynthetic oxygen production can cause problems. Conversely, wind causes turbulence of the surface waters and allows greater diffusion of atmospheric oxygen into the water. Acute anoxia can often be traced to a combination of biological and climatic factors.

Fish species vary in their tolerance to conditions of low dissolved oxygen. Some cultured species are air breathers and these fish are least affected e.g. the snakehead (*Channa*) and Catfish (*Clarias*) species. *Oreochromis* species (tilapia) depend on dissolved oxygen in the water but are less sensitive than the carp family (Cyprinidae) to conditions of low oxygen. Short term tolerance of low oxygen is not the only factor of importance and should be carefully related to the culture situation. Sub-lethal effects such as reduced growth rate at low oxygen levels, even in resistant species, are potential problems which do not have the dramatic manifestation of the fish kill, but can be just as economically debilitating.

2.9.8.2 Toxic Products

In intensive fish culture systems, where fish are stocked at high densities and fed large amounts of expensive feed, other aspects of water quality can also become problematic. In waste-fed ponds, fish are less densely stocked and potentially toxic waste products are usually absorbed into the natural food production before acute toxicity levels are reached. Ammonia, for example, which is an excretory product of the fish, and extremely toxic, is usually quickly taken up and utilized by the phytoplankton and bacteria in the water column. The blue-green algae in particular, by way of some unique physiological processes, are capable of assimilating large amounts of ammonia. Adequate water quality can be maintained even in intensive fish culture system (Rijn et-al., 1984) which heavily load nitrogen into the system. A sudden die-off of the algae bloom or increase in fish density, which removes the algae by grazing, can also cause dangerous increases in ammonia. Hopkin and Cruz (1982), however, found depressed

growth and survival of common carp in ponds that were heavily fertilized with chicken manure, and suspected this to be due to toxicity from ammonia. The well observed phenomenon of end of season inhibition of fish growth, in both intensive monoculture and integrated systems alike, may be correlated with the accumulation of toxic compounds e.g. sulphide in the sediments. The possibility of growth inhibition from chemicals produced by the fish themselves (pheromones) has also been suggested.

2.9.9 Management of Waste-Fed Ponds

The management goal for a waste-fed pond depends on the primary objectives. In most cases, the main goal is the maximization of revenue, which often, but not always, coincides with the achievement of maximum production in such systems. Strictly speaking, production would be increased to the point at which further production would reduce revenue.

In other cases, a primary objective may be to utilize wastes. Under these circumstances the addition of wastes would be continued to a level at which risks of overload and killing fish increased unacceptably, or to the point where wastes were not removed effectively.

The stimulation of natural food production in the pond, and its maximum utilization by the fish, must be the primary consideration but this must be balanced by the maintenance of adequate water quality. The waste feed eutrophic pond is more productive than a natural pond, but it also less stable. Variations in water quality, especially the dissolved oxygen level may be harmful to fish growth, or even cause acute mortality. This instability can be reduced by judicious management, however. The adjustment of inputs to the ponds biological and physical capacity to use them is part of this management. There is also evidence that a balanced variety of fish species may reduce the volatile and undesirable changes common among the pond food organisms which typically trigger large changes in water quality.

2.9.9.1 Addition of wastes

Traditionally, waste addition is managed by observing the colour of pond water and fish behavior in the early morning. More inputs are added if the water is not green enough and hence providing insufficient food production. Amount added are carefully controlled to avoid over production and anoxia. If fish are gasping at the surface of the water or if the colour is too intense, waste input is reduced and water may be exchanged. Zweig (1984) observed that these methods are not easy to quantify and rely greatly on the skill and experienced of the individual. Although used successfully in China, they may be difficult to transfer to other countries. Some operators recommend that if the arm is immersed in the water to the elbow and the palm of the hand can still be seen, there is a lack natural food and more input are required.

The risk of anoxia through over use of waste stands as the most important limitation to the amount of waste that can be added to the pond. More quantifiable approaches can be made by using general loading guidelines, by measuring phytoplankton density directly and by determining the potential of individual waste to break down and enter the pond's nutrient cycle and the stimulate production. The matching of these more scientific methods with an appreciation of practical indicators can enable a rapid and effective management approach to be developed.

2.9.9.2 Conditions of Waste

In practical terms it may difficult to add waste at the rate which best fit the requirement for both natural food production and a healthy environment for the fish. Waste, whether of plant or animal origin, are often of inconsistent quality of quantity throughout a growing season. Similarly, the requirement of the fish may be changed with time. If possible, integrated farming operations should be synchronized to meet the changing quantity of waste and the changing needs of fish production. In terms of their value as material for heterotrophic food chains, waste should finely be fragmented and easily dispersible in water. This allows the maximum surface area for colonization by heterotrophs and their rapid assimilation into the

pond food web, and permit a more effective distribution through the water body. The value of very fibrous materials to heterotrophs compared to shorter chain carbohydrate has been questioned (Schroeder, 1978). Higher yields of bacterial cells were found on chicken manure than the more fibrous cow manure, for instance. Liquid manure is usually of a more homogenous and easily dispersed nature, which enables greater predictability of its action on the ponds food web. Age and method of storage will also affect conditions of waste and their effectiveness as pond input.

2.9.9.3 Frequency and timing of waste addition

The efficiency with which waste are used in the food web appears to be affected by the frequency of the addition. Large occasional doses of waste tend to stimulate a massive and unstable growth of bacterial, and phytoplankton, with the consequent risk of acute night time oxygen depletion. Growth of adequate grazers (mainly protozoa and zooplankton) to control these primary producers tend to lag behind. More frequent addition of manure allows the establishments of a more balanced food chain, ensuring that particular organism do not reach exclusive levels. Regular addition also minimizes nutrient loses, since a larger, more balanced food web can absorb them more effectively.

When these matters are considered, it is not surprising that the pond systems that used the largest amount of waste do so on a continual or very regular basis. Maximum loadings in such situation are estimated to be in the range of 100-200 kg of manure dry weight/ha/day (equivalent 70 -140 kg of organic matter/ha/day) (Edwards, 1982). These practices contrast strongly with traditional European practice in which the pond bottom is covered with manures, or wastes are piled in anaerobic heaps, practices which do not aid the oxygen regime of the pond or the distribution and use of nutrients within the waste. If applied daily, the timing of waste addition should be such that the capacity for the pond to use it effectively is at its greatest. Mid morning, when oxygen content is rising fast through the photosynthesis of the algae, is properly the best time for manure addition.

The reasons for the notorious instability of waste feed ponds are still poorly understood, but sudden changes in water quality are usually linked to the collapse of algal blooms. An acute reduction of dissolved oxygen and increase in ammonia concentration typically follow algal die off. Temporarily, nutrient deficiency is possible a contributory factor in the collapse algal blooms and this is best avoided by continual waste addition. Eutrophic fish ponds tend to be dominated by blue green algae, which have favourable characteristics in terms of feed quality and oxygen production. Colman and Edwards (1985) have found that heavy fertilization, especially with organic waste coupled with seeding *Microcystis* sp. will produce a stable and productive basis for tilapia culture. Nutrients analysis of waste-feed ponds can indicate the pathways of loss and conservation from the water. Edwards (1983) suggests that nitrogen is more likely to be limiting for bacteria and phytoplankton growth giving the nitrogen to phosphorus ratio of livestock manures. Earlier work (e.g. Hickling, 1962), suggested that phosphorus was the main limiting nutrient, but this was on basis of very extensive system where biological fixation could provide the low levels of nitrogen required.

2.9.9.4 Waste addition and the weather

Prevailing conditions of temperature and light are important in determining the levels of wastes that can be safely added to fish ponds. Reduced ambient temperatures slow down bacterial decomposition of wastes, and the rate of growth of the food web generally. A build-up of organic matter in the sediments is possible if inputs are not adjusted, which can lead to undesirable conditions as and when temperatures do not rise. Cloudy periods resulting in reduced incident light energy and hence photosynthesis, also depress the pond system's ability to utilize large amounts of wastes. Seasonal adjustments in the amounts of wastes used are therefore necessary to prevent over or under-production of food.

2.10 Pond System

A typical use of pond system is in growing warm water species from fry to fingerlings. The ponds are initially filled with water and fertilized to create a natural growth of aquatic organisms to provide a natural food source for the fry.

2.10.1 Recirculating System

The advantage of recirculating system is that a high-density of fish can be kept at optimum temperature by removing the fish waste and reusing the water. An effective wastewater treatment system will usually include a settling tank followed by a bio filter. The bio filter provides a medium for aerobic bacterial to convert organic fish waste and ammonia into their cell mass and then it is remained as a settle able sludge.

2.11 Steps Involved In Fish Pond Construction

There are certain basic facts farmers need to know about the construction of fish pond before going into it. The steps involved in fishpond construction are as follows: -

2.11.1 Selection of site

The first step in fishpond establishment is the selection of the site. The site to be selected must have a good source of on water and topography must be favourable (Durojaiye 2001). The soil must be able to retain water and the site must be accessible.

2.11.2 Clearing of site

After locating a site, it is then cleared of vegetation to allow for easy movement and other activities (Durojaiye 2001). The clearing may be done manually if the vegetation cover is not thick or machined can be used for the clearing if the vegetation is denser.

2.11.3 Surveying of site

Surveying of the site could be as simple as visual/recognizance survey or detailed survey/topographic survey. The visual survey involves the farmer going to the site to make visual recognition of soil type, location of water, topography and the vegetation of the site (Durojaiye 2001). Topographic survey may be conducted to determine the shape of the land

with reference to sea level . It will assist in determining the position where water control structures like the monk, spillway, inlet canal and other structures can be placed to facilitate water flow by gravity.

2.11.4 Designing

It is important that the ideal height of pond should not be less than one meter (Durojaiye, 2001). If it is less, water in pond should become heated up and then there will be temperature problem, it should not be more than 2.5m in height so that light can reach all the levels of the pond.

2.11.5 Costs

A pond can be expensive, but a worthwhile endeavour. Many factors can influence the cost of pond construction (Monroe country water and soil conservation district, (2005)).

2.11.6 Pond Capacity

Pond capacity is important when sizing the pump and filter and when determining the correct dosage of plant fertilizers, algacides, and other chemical treatments. The most accurate way to determine pond capacity is to attach a flow meter to the faucet or water supply line and record the number of gallons needed to fill the pond (Terri, 2005). E suggested a less accurate, but easier and less expensive, method is to follow the basic formula as follows;

Rectangular Ponds: Length x width x depth x 7.5 = gallons

Circular ponds: Diameter x Depth x 5.9 = gallons

Oval ponds: Depth x width x length x 6.7 = gallons

Irregular ponds: It is difficult to calculate accurately the volume of an irregularly shaped pond. The best way is to determine the average width and length, and then use the equation for oval pond above.

2.11.7 Adequate water supply

Generally, for the successful operation of fishponds, suitable source of water must be available to the site (Wokoma and Ezenwa, 1982). They also stated that there should be enough water to fill the pond and maintain desirable water level, which will not fluctuate more than 60 cm during the dry month.

The most important consideration for fish culture is the supply of water. Even in a re-circulating system, substantial quantities of water are required. A well-designed re-circulating system consumed 10% or less of total water volume per day. If a culture system contains 50,000 gallons, the producer must plan for a consumption rate of at least 5,000 gallon per day, (Rosati, 2005). He also observed that if a pipe was running 24 hours per day to supply only this use, approximately 3.5 gallon per minute (GPM) must be supplied. Supply rates for farmsteads that include fish production as a major farm component is at least 20 – 40 GPM.

Table 2.6: Concentration of incoming water into the pond

VARIABLE	WARM WATER FISH
Dissolved oxygen	6-saturation
Carbon dioxide	0-10
Total alkalinity (as CaCO_3)	50-4000
pH	6.5 – 9.0
Total hardness (as CaCO_3)	20-4000
Calcium	10-160
Iron	0-0.5
Hydrogen sulphide <0.05	<0.005 un-ionized ammonia
Total dissolved gases	<105% total gas pressure
Salinity (value for catfish)	100-8,000
Temperature	appropriate for species

Source: Viveen *et al.* 1986

Table 2.7: Water quality requirement of catfish maintained in hatcheries and pond.

Eggs larvae-fry	fingerlings	adults
O ₂ close to saturation	>3ppm	>3ppm
T ⁰ C 20-30 ⁰ C, opt. 27 ⁰ C	20-30, opt. 27 ⁰ C	20-30 opt. 25 ⁰ C
PH	>6.5-8	
N ₂	< 102% saturation***	
CO ₂	<15ppm	
NH ₃	<0.05ppm	
NH ₄ ⁺	<8.86ppm (pH7).	
NO ₂ ⁻	<0.25 ppm	
NO ₃ ⁻	<250 ppm	
Cu	<0.03ppm	
Zn	<0.1 ppm	
Cd	<0.0006 ppm	
Salinity	<15000ppm	

Source: Viveen *et al.* 1986

TABLE 2.8: The solubility (100% saturation) of oxygen (O₂) in parts per million (ppm) in relation to the water temperature (°C) at an atmospheric pressure of 1 atmosphere.

°C	Ppm O ₂	°C	ppm O ₂
20	9.1	26	8.1
21	8.9	27	7.9
22	8.7	28	7.8
23	8.6	29	7.7
24	8.4	30	7.5
25	8.2		

Source: Viveen *et al* 1986

TABLE 2.9: The solubility (100% saturation of Nitrogen) in parts per million ppm in relation to the water temperature ($^{\circ}\text{C}$) at an atmospheric pressure of 1 atmosphere.

$^{\circ}\text{C}$	Ppm N_2	$^{\circ}\text{C}$	ppm N_2
20	14.9	26	13.4
21	14.6	27	13.2
22	14.4	27	13.0
23	13.9	29	12.8
24	13.9	30	12.6
25	13.6		

Source: Viveen *et al.* 1986

Incoming water should meet these values (concentrations are given in parts per million) as given in Tables 2.6 and 2.7. The solubilities of oxygen and nitrogen at various water temperatures are also given in tables 2.8 and 2.9 respectively.

2.11.8 Stocking of Pond

Stocking of pond is necessary to reach a healthy balance between the fish in the pond. According to Terri (2005), each fish should have 37.5cm^2 to 0.092m^2 of water. That an area of $0.093\text{m} \times 0.093\text{m}$ supports a fish 5cm long. An area three times as big accommodates three such small fish or 0.42cm fish. This is as shown in the Table 2.10

2.11.9 Stocking Rate and Ratio

The number of fish to be stocked in a pond per unit area and the standard of some species in monoculture as observed by Durojaiye (2001) is as follows:

Tilapia 10,000 – 20,000/ha, Carp – 3,000 – 6,000 /ha and Clarias 5000/ha

The relative number of fish species to be stocked in a polyculture pond is as follows

Tilapia + Clarias 40,000 6:1, Tilapia + Carp 5,000 1:1, Tilapia + Carp 5,000 3:1 and Clarias + Heterotis 4,000 1:2

Blakely and Hrusa, (1989), stated that when stocking catfish (*Clarias gariepinus*), the fry can be stocked in densities like 10,000- 15,000 fry / m^2 . He equally observed that the water depth should be 1-2m and the fish should have grown for up-to 2-3 weeks when they can then be transferred to production ponds. He reported that the stocking is at 10-30 fishes/ m^2 .

2.12 Basic Component of Pond Design and Construction

Each component of a well-constructed pond has a specific function and if omitted could lead to pond failure (Monroe country soil and water conservation district, 2005).

1. The dam is an earth embankment designed to impound water. It must be constructed of material that has a high clay and silt content and is well compacted. As the dam is

Table 2.10: Stocking of fish in cm/m^2 .

Size in cm	Space per m^2
5	0.093
10	10.8
15	0.278
20	0.370
30	0.556

Source: Teri 2005

built, the material should be added in no more than 150mm layers and compacted. Good dam construction is essential.

2. The core trench is another essential element of a pond. It is constructed by digging a trench the length of the dam. The trench should be dug beneath the dam to a depth of 600mm below the proposed pond bottom elevation. The core should be filled in with the same material that the dam is built with and compacted in the same manner. Poor core trench construction or the lack of one all together, is one of the major reasons a pond will leak and go dry in the summer.
3. The side slopes are described by using a ratio of horizontal to vertical distance along the slope. The slope of the backside of the dam should be a minimum of 3:1 for stability. If there is any plan to mow it, the backside should be at least 6:1. The slope of the side of the dam facing the water should be 2:1. The slopes are constructed as the dam goes up. The grade of the side slope elsewhere around the pond will determine the type and amount of vegetation that will grow. Slopes flatter than 2:1 inside the pond will have more aquatic vegetation growth.
4. The top width of the dam should be a minimum of 3m wide. It should be seeded and a good vegetative cover should be maintained.
5. Original ground level.
6. The level of the principle spill way is that of the proposed water level. It should be able to handle most of the run off from the pond. There are many different types of principle spill ways, the one in the diagram is one type of drop inlet pipe spillway.
7. Anti-seep collars are flat plates attached to pipe inside the dam. They prevent water from seeping along the outside of the pipe if soils are not compacted properly around the pipe.
8. The emergency spillways are usually constructed of sod and build to the side of dam in native soil. It is there to handle excess flows as the result of a storm or spring thaw. It

will prevent water from rushing over the embankment and destroying the dam. The emergency spillway should be well seeded and maintained.

9. If the soils around the pond are not of the type that will adequately hold water, it is recommended to line the pond with at least a 300mm layer of soil with a high clay contact. This is called lining the pond.

2.12.1 Gates

The gates are important structures of a fishpond (Durojaiye, 2001). They can be regarded as the second most significant part of the pond. They control the ingress and egress of water in ponds thus, responsible for regulating the water level in ponds.

One of the important characteristics of a modern fish pond is that it must be drainable, this means, that it should be possible to empty the pond down to the last drop of water (Wokoma and Ezenwa, 2001). He observed that ponds are provided with water control mechanism the inlet (filling) and the outlets (draining).

2.12.2 Types of Gate

According to Durojaiye, (2001), Gates could be classified as primary or secondary. Primary or main gates are located on perimeter dyke and are biggest gates in pond and at times with multiple openings. They control the access of water from the water sources into the pond as well as movement of water in and out of the pond. They are constructed with reinforced concrete. Secondary gates are those constructed on the partition dykes and are used for regulating the level of water in the pond compartment. They may be made with pipes, concretes and at times wooden planks. Standard gates have functional parts such as the tide stem wall, sidewalls, floor, cut off wall, grooves cut walks.

The gates are designed with capacity to be able to drain or fill the pond. The location must be such that total drainage of pond is possible, firmly and securely situated and linked with the dyke to prevent seepage and collapse of the pond as well as having adequate number and size of grooves for slab or slot boards together with; filter nets or mesh screens. Two main

gate types are in use in aquaculture these are sluice and monk gates. Monk gate serves as outlet of the pond. It can also serve as emergency spillway to discharge water from pond. It is usually constructed to have the same height with the dyke and in such a way that there is always a space above the level of water in the pond (which is called the free board), (Durojaiye, 2001). Sluice gates are more popular because they are cheaper to construct and maintain, and will allow rapid discharge of water from the pond. The construction material is also concrete and the gates are blocked with wooden blocking boards. The sluice gate is usually located at the lowest point of the pond bed within the dyke base, such that the gradient of slope to the gate is in the ratio of 1 in 100 or 200 (Wokoma and Ezenwa, 1982). Component parts of concrete sluice gate are the floor and the two walls with grooves for sluice board.

2.12.3 Specification for monk size

There are specifications for different sizes of pond, for example, outlet diameter for 1 hectare fish pond is 0.3 – 0.4 m, 0.2 m for 0.5 ha, 0.1 m for 0.3 ha etc. (Durojaiye, 2001). The height of the monk is usually the height of the dyke. For a monk of 1–1.5 ha ponds, the dorsal width should be 0.7m, lateral wall should be about 0.44m. Concrete thickness should be 0.12m and the grooves should be 0.04m, diameter of pipe can range from 0.15 – 0.3m

The monk wall is constructed with concrete and the concrete mixture is usually of cement; gravel and sand mixed at ratio 1:4:6 in head pan. There could also be reinforcement with $\frac{1}{2}$ inch or $\frac{1}{4}$ inch metal rods. Ideally a monk should be 0.5 – 1.5m to dyke base to prevent erosion. This is usually done by protruding the base of the monk.

2.12.4 Spillway

The spillway acts like a safety valve, which takes care of excess water caused by floods in some ponds especially when the reservoir has a river or stream as its source of water supply (Wokoma and Ezenwa, 1982). The concrete box spillway allows raising and lowering the water level with boards (Monroe country soil and water conservation district, 1993).

2.12.5 Content of any Cultural Building

According to Rosati (2005), pond must contain the equipment requirement to perform the following functions:

1. manipulate the ambient environment especially temperature,
2. contain water,
3. remove ammonia or convert it to a less toxic form,
4. separate solid waste from culture water,
5. treat and dispose of solid wastes,
6. add oxygen,
7. remove carbon dioxide,
8. feed fish,
9. monitor system components and alert farmer to component failure and
10. allow fish containment, manipulation and harvest

2.12.6 Pond Maintenance

According to Terri (2005), pond maintenance should embrace the following:

- i The pH level should lie between 6.5 and 8.5 because fish do well at such pH.
- ii Removal of dead leaves and plants from the pond because they cause water to become acidic; lime, leaching from concrete, cement or mortar could cause water to be alkaline.
- iii Planting of root growing plants because oxygenated plants assist in keeping pond water in a healthy range.
- iv Animal burrowing into the pond should be avoided by using Poultry wire fence or thick layers of sand or gravel and
- v change 20 percent of water in the pond each month to ensure a healthier pond

2.13 Concrete/homestead tanks

Despite high cost of rental price of land, land availability in urban centers is inadequate as existing land had been committed to commercial, industrial, residential and recreational uses with little or no consideration for agricultural food production. It is a common practice for building contractors in urban centres to construct rectangular concrete-block tanks for water storage prior to commencement of building works and on completion of the building projects, the tanks would have outlived their purpose and are therefore dismantled. The dimensions of the tanks constructed vary with size of the proposed building. The conversion of these tanks into functional fish culture enclosures is being developed and improved as a possible transition between the traditional tidal pool/floodplain culture and the modern conventional pond culture.

The suitability and acceptance of concrete-block tanks as enclosure for fish culture lie in the inherent properties. Fagbenro 1987, outlined some of the advantages associated with the use of concrete tanks as follows;

2.13.1 Economic aspects

- i) Sites required for establishing homestead tanks demand no acquisition costs and are not dependent on conventional demands of pond culture such as natural water source, topography, clay content and alkalinity of soils, therefore costs of land clearing, water diversion, site survey, soil tests and improvement of poor soils are saved.
- ii) Construction does not require advanced technology or mechanization thereby limiting costs to the barest minimum as labour, equipment and time used on land clearing; stumping and removal of vegetation; soil profiling; excavation and earth movement in constructing earthen ponds are not required.
- iii) Due to small size and shallowness of homestead tanks, the carrying capacity is low and therefore fewer fish seeds are required for stocking.

- iv) Operational costs are reduced also due to small size as well as the availability and utilization of livestock/poultry wastes as organic fertilizer with or without inexpensive feedstuffs/household scraps as supplementary food.
- v) Total drainage is possible and water level easily controlled without using additional labour, fish catching device or fish holding utensils during harvesting. Fish storage; preservation and transportation are not required as all fish harvested are either consumed or sold locally.

2.13.2 Biological aspects

- i) Productivity (algal growth) in water is high due to shallowness of tanks thereby ensuring provision of abundant natural food for fish stock.
- ii) When fishes are crowded into small space (like homestead tanks), they burn fewer calories, consequently food conversion is more efficient.
- iii) Growth and health of fish stock are observed and monitored easily, therefore disease outbreaks are detected early and controlled while predators and/or competitors are eliminated resulting in high survival rate of fish stock.

2.13.3 Management aspect

- i) Water quality and quantity are easily monitored and problems of water seepage through walls, erosion of walls, and risk of pollution of water do not arise.
- ii) Due to shallowness of tanks and absence of earthen walls, the emergence of aquatic weeds is effectively prevented.

2.13.4 Social and health aspects

- i) Commencement of construction is possible irrespective of prevalent season or climate as opposed to construction of earthen ponds preferably during the dry season.
- ii) The enterprise can be expanded or discontinued as desired at little additional costs.

iii) Health hazards posed by water-related insect borne diseases like malaria, bilharzias and onchocercariasis are not encouraged. Moreover, fish species selected for stocking feed on larval stages of mosquitoes.

2.13.5 Constraints to fish culture in homestead tanks

Fagbenro 1987, stated that the main constraints to the establishment and development of fish culture in homestead tanks include among others, a) low awareness, b) initial capital input, c) source and cost of fish seeds and d) tap water supply.

3. MATERIALS AND METHODS

3.1 Study Area

The research was carried out at the Teaching and Research Farm of the Department of Agricultural Engineering, Federal University of Technology, Akure in Ondo State, Nigeria (Fig.3.1). Akure is located within the humid region of Nigeria on latitude $7^{\circ}16' \text{ N}$; longitude $5^{\circ}13' \text{ N}$. The area has a general elevation of between 300 – 700 meters above sea level. Local peaks rise to 1000 meters; other hill – like structures which are less prominent rise only a few hundred meters above the general elevations. The average annual population growth rate according to the 2004 estimate was 2.4%. It has a population of about 483,300 (Population census, March 2006 estimate) and has a land area of about 2,303 sq km. It is situated within the Western upland area. This has resulted in an increase in the population, putting pressure on the natural resources both land and water.

The climate in Akure is controlled primarily by the continental air mass or North East Trade Winds and the tropical maritime air mass or South West Monsoon Wind. Rainfall is governed by the annual passage of the Inter-Tropical Convergence Zone (ITCZ), the meeting point of a dry northeastern low – pressure air mass and a moist southwestern high – pressure air mass. The northeastern movement of the ITCZ and the rain-bearing winds that accompany it mark the onset of the rainy season. Its southwestward movement and the accompanying harmattan winds mark the beginning of the dry season. Annual rainfall and its reliability decrease from the south northwards. The pattern of rainfall is bimodal, the peak occurring in June – July, and the second in September, with dry spell in August (Adefolalu, 1972, 1973) the mean annual rainfall ranges between 1300 mm to 1500 mm. More than half of humid zone of Nigeria is covered by Pre-Cambrian basement complex (Rahaman 1976, and Asiwaju-Bello, 1999). It is principally composed of metamorphic and igneous materials. A gently rising ridge



FIGURE 3.1: THE MAP OF ONDO STATE OF NIGERIA

of quartzite occurs in the upstream part (north) of the area while pavement outcrops of biotite gneiss are found a few hundreds of meters downstream, South of a perennial spring). There is a residual soil cover of dark reddish to light brown medium – grained lateritic material around the spring outlet. The spring falls within the fifth order of meinzers classification (Asiwaju-Bello, 1999). The soils are light textured, fine sandy loam to fine sandy clay loam. The soil is moderately well supplied organic matter and nutrients. Moisture holding capacity is moderately good. The soil of the environment is however subject to seasonal water logging for varying periods, but become dry during the dry seasons

3.2 The Poultry Housing and Fish Tank

The housing was designed with special emphasis on the cost of materials of construction, availability, durability and environment or site of the husbandry.

3.2.1 Cage Dimension

Height of the cage	=	47 cm
Width of the cage	=	49 cm
Length of the cage	=	50 cm
Floor area of the cage	=	50 cm x 40 cm (0.2 m ²)

The height slopes down to 37cm at the back while the floor extends at least 15cm to form an egg cradle at the front as shown in Figure 3.2.

3.2.2 The Cage

The cage floor slab is made of steel wire mesh to give optimum delivery of the poultry waste.

3.2.3 Poultry House Dimension

Length of the house	=	4.50 m
Breadth of the house	=	2.54 m
Floor area of the house	=	4.50 m x 2.54 m = 11.43 m ²

In order to have adequate ventilation, the height of the house = 2.4m. The working views is as shown in Figure 3.3

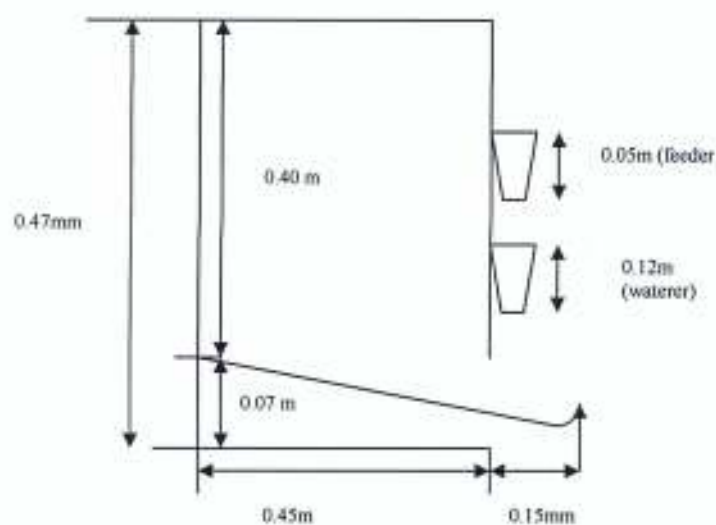


Fig. 3.2: The battery Cage Dimensions

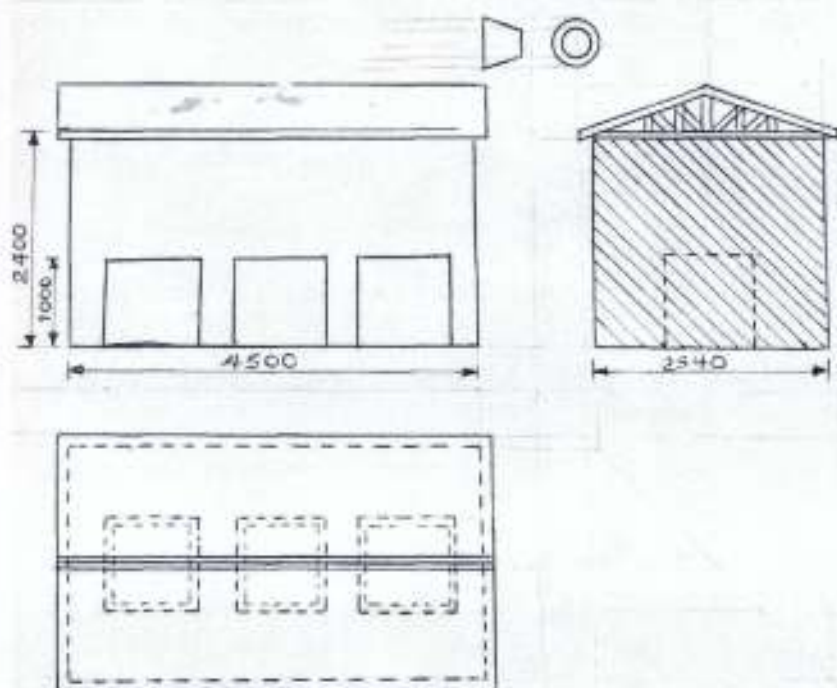


Fig 3.3: The working views of the husbandry

3.3 The Roof Design

The sketch of the assumed roof pattern is shown in Figure 3.4. The height, slope and number of trusses of the roof were determined as follows:

According to (Kazim and Jindal, 1989), king post size for the truss is the eave height and is always $\frac{1}{4}$ of the clear span of the truss.

$$\text{King post size} = \frac{1}{4} \times 2.54\text{m} = 0.64 \text{ m}$$

$$\text{Clear span of the roof} = 2.54\text{m}$$

$$\text{Allowance for overhang on both sides} = 0.36\text{m}$$

$$\text{Therefore, clear span of the truss} = (2.54 + 0.36) \text{ m} = 2.90 \text{ m.}$$

$$\text{Adopting a pitch of } \frac{1}{4}, \text{ height of truss} = \frac{2.9}{4} = 0.715\text{m}$$

For short span trusses, the economical spacing varies from 5 – 7m (Kazim and Jindal, 1989).

However, the width of the building is 4.5m. 2 trusses ok.

The span is less than 6m; hence a king-post roof truss is recommended.

3.3.1. Estimation of live load

The live load was estimated using (Kazim and Jindal, (1989)) which stated that where access to roof is not provided, except for maintenance, for roof slope greater than 10 degrees, a live load of 75kg/m^2 less than one kg/m^2 for every degree increase in slope up to and including 20 degrees and 2 kg/m^2 for every degree increase in slope over 20 degrees should be allowed.

$$\text{Slope angle of roof} = \tan^{-1} \frac{0.715}{1.27} = 29.38^\circ$$

$$\text{Live load} = (75 - 10 \times 1) - (9.4 \times 2) = 46.2 \text{ kg/m}^2 \text{ on a horizontal plane}$$

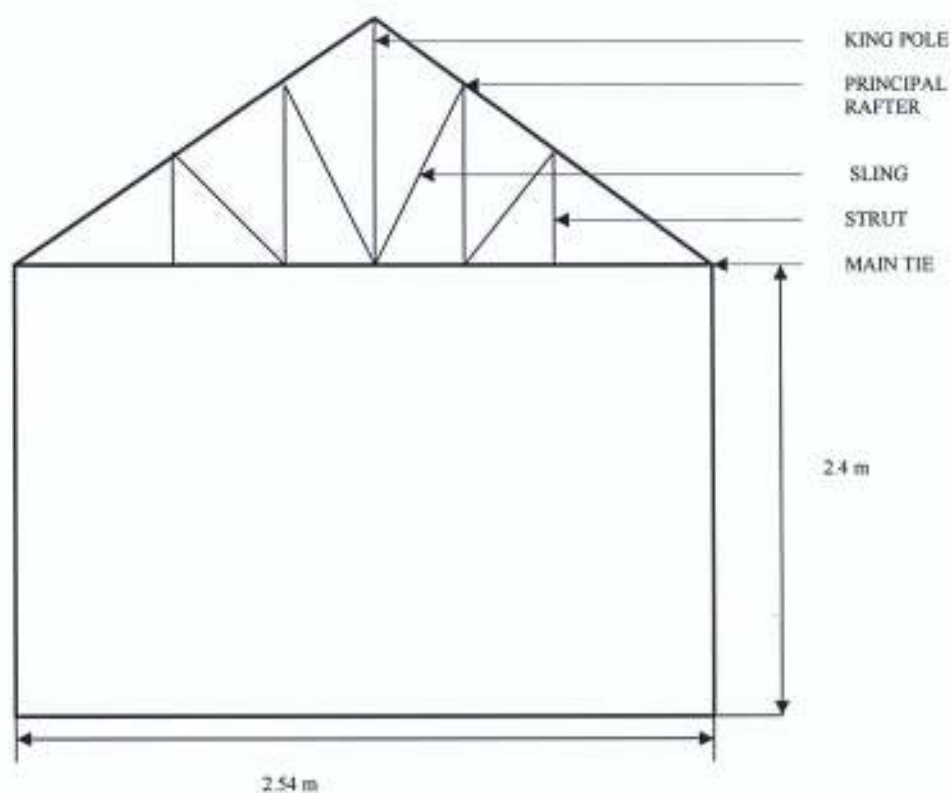


Figure. 3.4: The Roof Structure

3.3.2. Wind load

Basic wind pressure was calculated from the equation given by Breyer (1982), i.e. wind pressure, $P = C_e C_q q_s l$. (3.1)

Where C_e = wind load combine height, exposure and gust factor

C_q = wind load pressure coefficient = 0.7 leeward roof

l = moment of inertial of members = 1.0 for non essential buildings

For wind velocity = 31.5m/s, $C_e = 1.2$ for height 0-6m, $q_s = 0.62 \text{ kN/m}^2$.

$P = 0.52 \text{ kN/m}^2$ or 53.06 kg/m^2 .

For the estimation of this parameter, external wind pressure and internal wind pressures were estimated using the data based on large openings, from the table given by Kazim and Jindal (1989), for roof pitch 30° , a value -0.6 is given as wind pressures on windward direction.

a) Wind normal to ridge

Internal pressure on windward slope = $-0.6 P = 31.84 \text{ kg/m}^2$

Internal pressure on leeward slope = $-1.0 P = -53.06 \text{ kg/m}^2$

Internal suction on windward slope = $0.4P = 21.24 \text{ kg/m}^2$

Internal suction on leeward slope is zero since the building has large permeability.

Wind load parallel to ridge

On windward slope = $-0.8P = -42.45 \text{ kg/m}^2$

On leeward slope = $-0.8P = -42.45 \text{ kg/m}^2$

Thus from the above, the maximum wind pressure could be -42.45 kg/m^2 and occurs when wind blows parallel to ridge.

3.3.3. Design of Purlins

The maximum permissible span for galvanized iron roof is 1.8m and the following two load combinations will be considered for the design of purlins and the greater value of total load will be adopted.

1. Dead load + live load
2. Dead load + wind load

Weight of corrugated galvanized sheet per length of the purlin = $6 \times 1.8 = 10.8 \text{ kg}$

Weight of wooden purlin per meter length = 2.5 kg

So dead weight / meter length of purlin = $10 + 2.5 = 12.5 \text{ kg}$

Live load/meter length of purlin = $46.2 \times 1.8 \cos 29.4^\circ = 72.45 \text{ kg}$

Wind load/meter length of purlins = $-42.45 \times 1.8 = -76.41 \text{ kg}$

Dead load + live load = $12.5 \text{ kg} + 72.45 \text{ kg} = 84.95 \text{ kg}$

Dead load + wind load = $12.5 \text{ kg} - 76.41 = -63.91 \text{ kg}$

Negative sign indicates that there would be suction or uplift pressure on the roof of the truss. Hence 84.95 kg would be used for the design of the members.

$$\text{Maximum bending } (\sigma) = \frac{pl}{8} = \frac{84.95 \times 4.5}{8} = 47.78 \text{ kgm}$$

$$\sigma = \frac{M_{\max}}{I} y_{\max} \quad (3.2)$$

$$\sigma = \frac{47.78 \times 1000 \times dx \times 12}{2bd^3} \leq 9$$

$$bd^2 \geq 31,853.33$$

50 mm x 75 mm wood of SC3 is ok

3.3.4. Stresses in members

There are six panels of the truss, it is necessary to calculate load acting on each of the panel points. The load per panel length is calculated as follows;

$$\text{Weight of sheeting} = 3.5 \times 1.8 \times 4.5 = 28.35 \text{ kg}$$

Weight of one truss = $6 \times 2.54 \times 4.5 = 68.58 \text{ kg}$

Weight of purlin = $5 \times 4.5 = 22.5 \text{ kg}$

There are 6 panels, hence weight of truss per panel length = $68.58/6 = 11.43 \text{ kg}$

Dead load per panel length = $28.35 + 22.5 + 11.43 = 62.28 \text{ kg}$ or 0.61 kN

Dead load on each shoe = $62.28/2 = 31.14 \text{ kg}$ or 0.31 kN

Live load per panel length = $46.7 \times 0.473 \times 4.5 \cos 30^\circ = 86.08 \text{ kg}$ or 0.84 kN

Live load on each shoe = $86.08/2 = 43.04 \text{ kg}$ or 0.42 kN

Wind load per panel length = $-0.8P \times 0.473 \times 4.5 = 90.35 \text{ kg}$ or 0.87 kN

Wind load per load on each shoe = $90.35/2 = 45.17 \text{ kg}$ or 0.44 kN

The load diagrams for dead load, live load and wind load acting on the truss is shown in Figure 3.5. The forces in the various members of the truss were estimate by the usual methods of analysis for each type of loading separately using the method of joints.

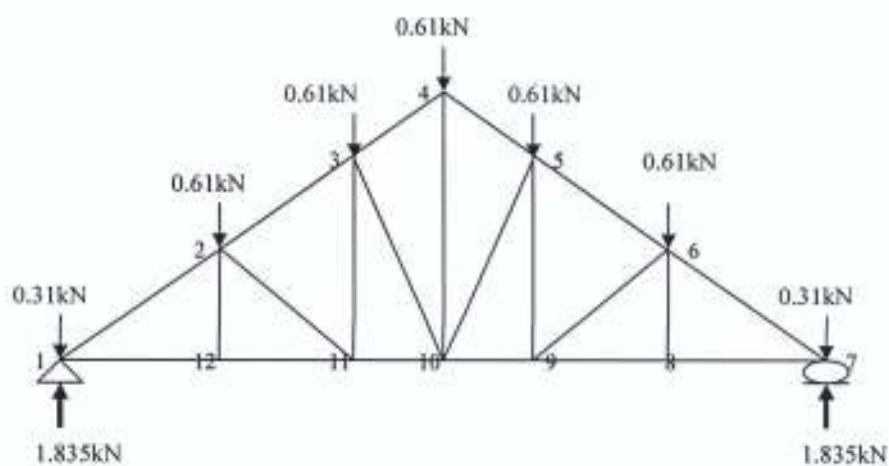
The stress in each member is calculated as shown in Appendix A1;

3.3.5. Selection of wooden sizes for structural members

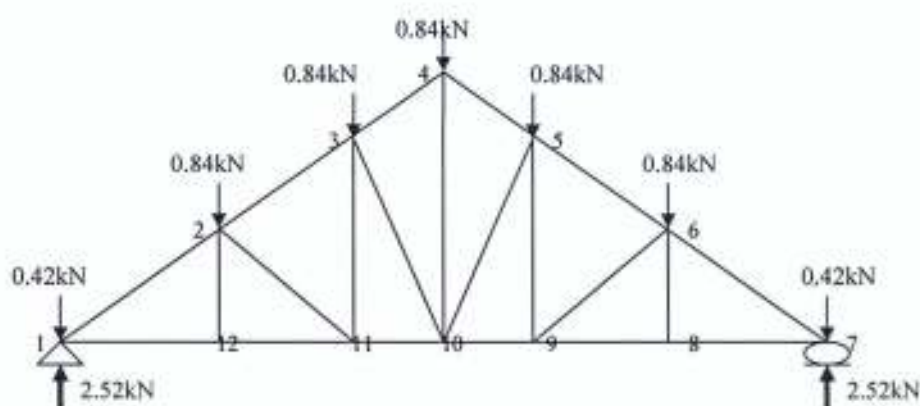
Main Rafter: From Table 3.1, the design forces (compression and tension) are 7.388 kN and -1.794 respectively. From design Tables given by Vincent and Billington (1992), $50 \text{ mm} \times 75 \text{ mm}$ with a spacing of 1.21 m white wood of class SC3 is ok

Bottom Chord (main tie): From Table 3.1, the design forces (compression and tension) are 1.115 -6.439 respectively. From design Tables given by Vincent and Billington (1992), $50 \text{ mm} \times 75 \text{ mm}$ with a spacing of 1.21 m white wood of class SC3 is ok

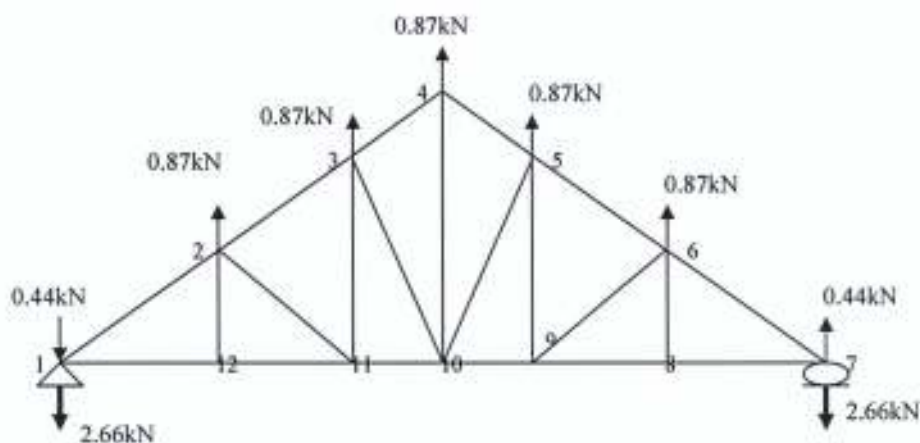
Struts: From Table 3.1, the design forces (compression and tension) are 1.196 and -3.26 . From design Tables given by Vincent and Billington (1992), $38 \text{ mm} \times 75 \text{ mm}$ white wood of class SC3 is ok.



A: dead Loads



B: Live Loads



C: Wind Loads

Fig. 3.5: Analysis of the Roof Truss

Slings: From Table 3.1, the design forces (compression and tension) are 2.02 kN and -0.425 kN. From design Tables given by Vincent and Billington (1992), 38 mm x 75 mm white wood of class SC3 is ok.

3.4 Integrated Poultry Housing Description

3.4.1 Tank Description

Rectangular tanks were made of sandcrete hollow block of 150 mm (6 inches) and constructed on simple strip concrete foundation. The tank consists of three cells of 1m³ each for three different treatments. The wall was plastered with sandcrete. One important characteristic of a homestead tank is that it must be drainable; this means that it should be possible to empty the pond down to the last drop of water hence the floor of the tank was constructed at a slope of 0.2 for proper drainage. The water control mechanism of the tank inlet (filling) is through rubber hose from an overhead tank and outlet (drainage) is through control valve of 1 ½ inches in each cell fitted to pressurized P.V.C pipe of 1 ½ inches and 0.5m long.

3.4.2 Poultry Housing Unit Description

The poultry-housing unit had a floor dimension of 4.50m by 2.54m and total height of the building was 3.14 m. It was constructed using timber and steel poles, which are readily available materials with good strength and minimum cost. The roof was made of galvanized corrugated roofing sheet. The cage was constructed using wood and wire mesh (1.5mm) for the cage floor. The height of the cage was 0.47m, length of 0.5m and width of 0.4m. The complete housing unit is as shown in Plate 3.1.

3.4.3 Effects of Environmental Variables on Poultry Performance and Water Quality

Performance evaluation test was carried out on the effects of environmental parameters such as relative humidity, temperature, heat and ventilation on the poultry birds as well as the pollution of pond water resulting from the droppings from the birds and wastes generated by the fish.

TABLE 3.1: Compressive and Tension Forces in the Structural Members

Truss	Member Forces (kN)					
Member	Dead Load	Imposed Load	Wind Load	Max Compression	Max Tension	Design force
1-2	3.108	4.28	-4.636	7.388	-1.528	7.388 -1.974 Rafters
2-3	2.50	3.42	-4.108	5.92	-1.608	
3-4	1.61	2.57	-3.584	4.18	-1.974	
4-5	1.61	2.57	-3.584	4.433	-1.974	
5-6	2.50	3.42	-4.108	5.92	-1.608	
6-7	3.11	4.28	-4.636	7.388	-1.528	
7-8	-2.709	-3.73	3.82	1.115	-6.439	1.115 -6.439 Bottom Chord (main tie)
8-9	-2.709	-3.73	3.82	1.115	-6.439	
9-10	-2.177	-2.984	2.94	0.763	-5.161	
10-11	-2.177	-2.984	2.94	0.763	-5.161	
11-12	-2.709	-3.73	3.82	1.115	-6.439	
12-1	-2.709	-3.73	3.82	1.115	-6.439	
2-12	0	0	0	0	0	1.196 -3.26 Struts
3-11	-0.304	-0.42	.50	0.196	-0.724	
4-10	-1.58	-1.68	2.00	0.42	-3.26	
5-9	-0.304	-0.42	0.499	0.196	-0.724	
6-8	0	0	0	0	0	
5-10	0.91	1.12	-1.335	2.02	-0.425	2.02 -0.425 Slings
6-9	0.61	0.86	-1.018	1.47	-0.408	
3-10	0.91	1.12	-1.335	2.02	-0.425	
2-11	0.61	0.86	-1.018	1.47	-0.408	

3.5 Experimental Procedure

The experiment was a single factor randomised complete block design (RCBD) with 4 treatments including a control. The treatments were replicated twice giving a total of eight tanks. One bird was placed on top of tank 1 while two birds were placed on top of tank and three birds were placed on top of tank while no bird was placed on the control pond. Growers mash was used to feed the broiler chickens throughout the period of the experiment. The experimental set up is as shown in Plate 3.1

Well-water was used to fill the tank prior to stocking of fish. Twenty juvenile catfish (*Clarias gariepinus*) of about 20 g were stocked into each tank and acclimatised to the culture conditions for five days preceding the start of the experiment. The water in each of the four tanks was changed every week. Weight and number of fish in each of the tanks were recorded every two weeks. Fish were harvested at the end of 168th days and the weight and number of fish harvested was recorded. In the case of control experiment, the fish were fed with a commercial fish feed (extruded floating feed). Growth response was determined as weight gain (WG), average daily growth (ADG) and specific growth rate (SGR) as follows:

$$\text{Weight gain (g)} = W_f - W_i$$

$$\text{Average daily growth (g/day)} = (W_f - W_i) / \text{experimental period (days)}$$

$$\text{Specific growth rate} = \frac{100 \times (\ln(W_f) - \ln(W_i))}{\text{experimental} \cdot \text{days}}$$

Where W_f = final fish weight

W_i = initial fish weight

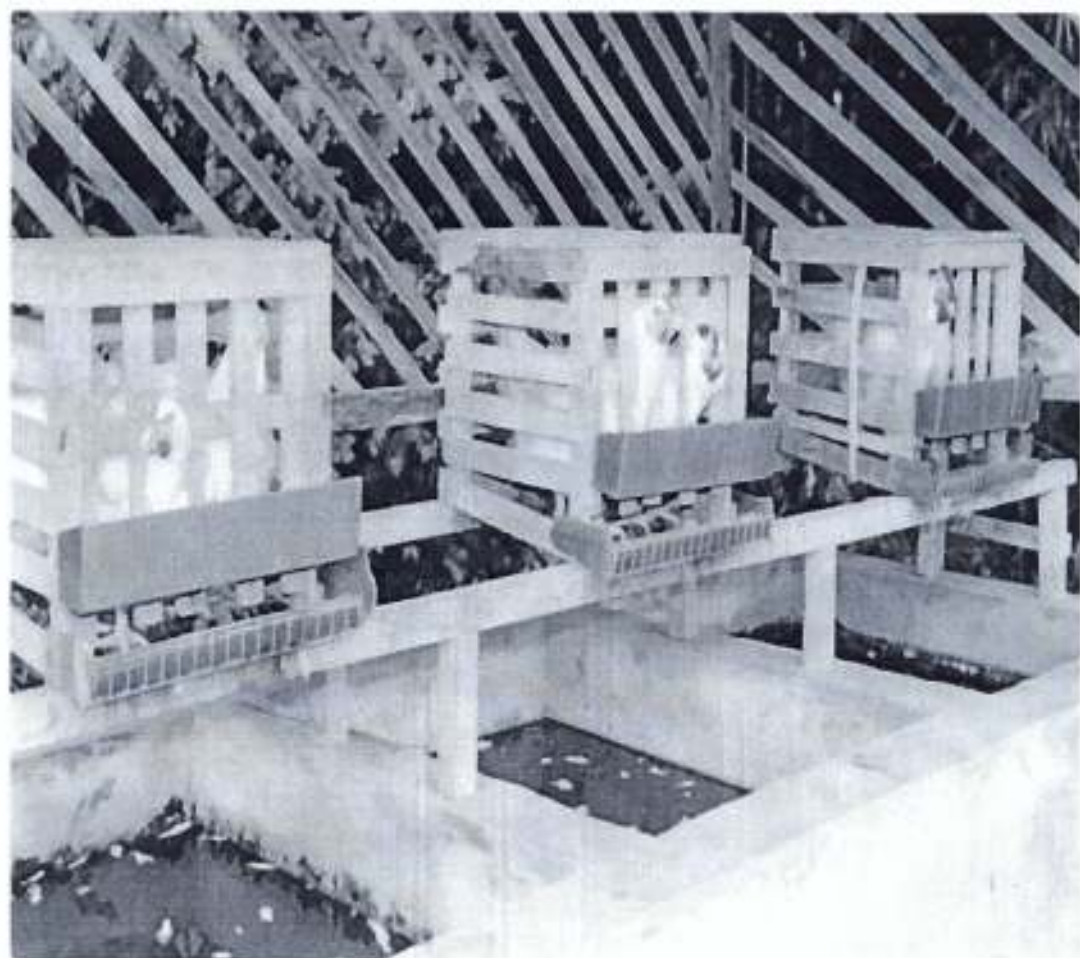


Plate 3.1: Integrated poultry/Fish experimental set up

Analysis of variance (ANOVA) test was conducted to determine the effect of feeding methods on growth indices. Significance differences were further assessed at 5% level of significance using least significance difference (LSD) test. The quantity of concentrates used to feed the fish in the control experiment was determined using their body weight as shown in Table 3.2.

Twelve four week old broilers were used for the experiment. Information about the age and other necessary immunisation status of birds were collected from the point of purchase at the University Teaching and Research farm.

3.6 Data Collection

3.6.1 Water and Water sampling techniques

The only source of water filling the tanks/surface is from a well at the experimental site about 4.5 m deep and located at the lower end of the experimental site. The water source yield adequate water that could be supplied to the tanks provided pumping is carried out periodically to an overhead tank. However, because of difficulty in digging below the water level, the well does not penetrate the zone of saturation to a depth sufficient to produce a high yield.

Water samples were collected from the tanks. All containers were rinsed with clean water before the water samples were taken from the tanks. The containers were filled with water sample to the brim and brought to the laboratory for water quality analyses. The analyses carried out on the water samples were only on the physical (direct) and chemical.

3.6.2 Water Quality Determination

Water temperature ($^{\circ}\text{C}$), Turbidity (NTU), pH, Conductivity ($\mu\text{scm-l}$) and Dissolved oxygen (mg/l), were measured directly using Horiba u.10 portable water analyzer checker.

TABLE 3.2: Feeding Table for Catfish Grow-out

Average weight (g)	Feeding level (%body weight)	Pellet size (mm)
5-10	5.5-6.0	2.0
10-25	4.5-5.5	2.0
25-70	4.0-4.5	3.0
100-250	3.0-4.0	4.5
500-750	1.5-2.0	4.5
750-1000	1.1-1.5	4.5 or 6.0
1000-1250	0.9-1.1	4.5 or 6.0
1250-1500	0.8-1.0	4.5 or 6.0
1500-2000	0.7-0.9	4.5 or 6.0

Source: Dizengoff (2005)

3.6.3 Physico-Chemical Analysis

The chemical parameters determined in the laboratory included the following;

Nitrite, Ammonia, Colour, Chemical Oxygen Demand, Biochemical Oxygen demand and Chloride. Standard test procedures given by given in FUTA laboratory were followed in the determination of the chemical parameters.

3.6.4 Temperature and Relative Humidity Measurement

Temperature and relative humidity were determined with a digital hygrothermometer. The readings were taken three times daily i.e. morning, afternoon and evening. The data collected are:

- i) Temperature and relative humidity outside the housing unit
- ii) Temperature and relative humidity inside the housing unit
- iii) Temperature and relative humidity under the poultry cage
- iv) Temperature and relative humidity inside each poultry cage

Continuous measurements were made for six (6) months. During this period the environmental parameters (temperature, relative humidity and air speed) and the growth of fish in the pond were monitored. Data collected were subjected to appropriate statistical analysis such as descriptive statistics, Analysis of Variance, and multiple and step-wise regression analysis.

3.6.5 Total Heat

The total heat inside all the cages in the integrated system was estimated. Heat flow is very important in moisture and heat balance methods of calculating ventilation rate. The parameters that were used include: mass of the birds and indoor temperature. Total heat could be calculated from the following equation presented by Pedersen *et al.*, (1998).

$$Q = 7m^{0.75} \quad (3.12)$$

Where Q = total heat energy produced as a result of metabolic activities in the body and m is mass of birds in kg. However the equation is only valid when the temperature is 20°C and when $t \neq 20^{\circ}\text{C}$, a correction factor is required, i.e.

$$q = jQ \quad (3.13)$$

Where $j = 4 \times 10^{-5}(t - 20)^3 + 1$ and this is dimensionless.

Animal heat balance can be evaluated from;

$$q = S + L \quad (3.14)$$

Where S and L are the sensible and latent heat production, respectively.

3.6.6 Estimation of Sensible Heat

The proportion of the total heat which appears as sensible heat, neglecting solar radiation, light etc was evaluated from the equation by Strom (1978) ;

$$S = lq \quad (3.15)$$

Where $l = 0.8 - 1.85 \times 10^{-7}(t + 10)^4$ and dimensionless (3.16)

Recent studies have shown that a proportion of the total heat production is used to evaporate water from faeces, urine and feed in the house. In this study, a proportion of the heat would be used to evaporate water from the surface of the pond too which could be estimated from the equation by Strom (1978);

$$S_n = k_s n S \quad (3.18)$$

where S_n is the corrected sensible heat (Watts), k_s is a factor ranging between 0.8 -1.0, n is the number of birds. The total sensible heat produced by the birds throughout the period of the experiment was estimated.

3.6.7 Estimation of Latent Heat

The latent heat inside all the cages was estimated using equation 3.19 (CIGR, 1995).

$$L = (1 - l)q \quad (3.19)$$

The data obtained were subjected to appropriate statistical analysis.

3.7 Modelling of Temperature and Humidity in Integrated Poultry/Fish Unit

3.7.1 System Model

The indoor climatic processes together with the building and the birds are considered to be a black box. This assumption allows focusing only on investigation of the links between the input and output variables, and the disturbances. Some input (U) factors (total heat (Q_i), ventilation (G_n), and total moisture produced (D_i) and disturbances (Z) which are outside temperature (t_a), moisture content of the outdoor air, g/kg (d_a) and wind velocity (V_w) have direct effect on the micro climate conditions inside the poultry house.

The input-controlling factors (U) and disturbances can be determined on the basis of theoretical relationships for heat and moisture balance as given by the following equations given by Seedorf *et-al.*, (1998):

$$Q_p - Q_v - Q_l - Q_e = c_p M_a \frac{d(t_s)}{dt} \quad (3.21)$$

$$D_p - D_v + D_a - D_e = \lambda V \frac{d(d_s)}{dt} \quad (3.22)$$

Where Q_p is sensible heat production of the birds, kW

Q_v is heat loss due to ventilation, kW

Q_l conductive heat losses through wall, ceiling and the floor of the building, kW

D_p is water vapour production of the birds, kg/h

D_v is rate of moisture transfer to the inside air leaving the building kg/h

D_a is rate of moisture transfer from the outside air entering the building, kg/h

D_e is rate of moisture transfer from the evaporation of water from the floor, kg/h

V is volume of airspace in the building m^3

c_p is specific heat of air, $kJ/kg^{\circ}C$

M_a is mass of air, kg

t_b is air temperature inside the building, $^{\circ}\text{C}$

t_a is temperature of the outdoor air, $^{\circ}\text{C}$

ρ is density of air, kg/m^3

The bird's heat production Q_p and the bird water vapour production D_p are non linear functions of the air temperature inside the building, t_b , the number of birds N_p and their mass M_p in kg are given by

$$Q_p = f(t_b, N_p, M_p) \quad (3.23)$$

$$D_p = f(t_b, N_p, M_p) \quad (3.24)$$

Heat loss as a result of ventilation Q_v are linear functions of the difference between inside t_b and outside air temperature and the total airflow G in to the building:

$$Q_v = f(t_a, t_b, G) \quad (3.25)$$

The total natural ventilation airflow G in a building can be represented by G_n originating from the cross ventilation and which actually depend on wind velocity:

$$G = f(G_n, V_w) \quad (3.26)$$

The conductive heat losses Q_l through the building walls, roof and floor are linear functions and depend on G , d_a , and d_b , where G_n is non controlled airflow (m^3/h), V_w is wind velocity,

$$d_a = f(t_b, d_a) \text{ where } d_a \text{ is moisture content of the outdoor air (g/kg),} \quad (3.27)$$

$$D_v = f(t_b, d_b) \text{ where } d_b \text{ moisture content of the air inside the building, g/kg} \quad (3.28)$$

Q_e and D_e are also linear functions of t_b and d_b for a small interval of change of inside air temperature t_b :

$$Q_e = f(t_b, d_b) \quad (3.29)$$

$$D_e = f(t_b, d_b) \quad (3.30)$$

On the basis of equations 3.21 – 3.30, the mathematical models describing the thermal and moisture processes of the indoor climate can be written as

$$\frac{d(t_b)}{dt} = f(Q_p, G_n, V_w, t_a, d_b, t_b) \quad (3.31)$$

$$\frac{d(d_h)}{dt} = f(Q_p, G_n, V_w, t_a, d_a, d_h) \quad (3.32)$$

The mutual relationship between air temperature t_a and air moisture d_h is clearly seen in equation 3.31 and 3.32. If in equation 3.31, the variable d_h is substituted by independent variables (D_p , G_n , V_w , d_a , and t_b , from equation 3.32, equation 3.31 becomes

$$\frac{d(t_b)}{dt} = f(Q_p, G_n, V_w, t_a, d_a, D_p, t_b) \quad (3.33)$$

By analogy substituting equation 3.31 into equation 3.32 yields

$$\frac{d(d_h)}{dt} = f(Q_p, G_n, V_w, t_a, d_a, D_p, d_h) \quad (3.34)$$

The bird heat production Q_p are rather inconvenient as expressed by equations 3.23 and 3.24, since they transform equation 3.33 and 3.34 into non linear form. Therefore Q_p and D_p are defined as independent input variables using the following equations by Pedersen *et al.* (1998).

$Q_p = 7m^{0.75}$. The equation is valid for $t = 20^{\circ}\text{C}$, but for $t > 20^{\circ}\text{C}$, a correction factor is required, i.e.

$$q = jQ \text{ where } j = 4 \times 10^{-5}(t - 20)^3 + 1 \quad (3.35)$$

$$q = S + L \quad (3.36)$$

Where S and L are sensible and latent heat production respectively.

Equation 3.17 can be written as

$$S = lq \quad (3.37)$$

Where $l = 0.8 - 1.85 \times 10^{-7}(t + 10)^4$ and represents the relative proportion of total heat which appears as sensible heat. Neglecting solar radiation, light etc, then

$$L = (1 - l)q \quad (3.38)$$

The partitioning of heat production has shown (CIGR1984) that a proportion of the total heat is used to evaporate water from faeces, urine and feed in the house. This effectively reduces the sensible heat losses from the buildings S by an amount k_s

$$S = k_s n S \quad (3.39)$$

k_s varies from 0.8-1, and n is the number of birds

According to Pedersen *et al.* (1998), the mathematical differential equation which combines all environmental factors is given as;

$$\frac{d(t_h)}{dt} = f(Q_i, G_a, V_a, t_a, d_a, D_i, t_h) \quad (3.40)$$

$$\frac{d(d_h)}{dt} = f(Q_i, G_a, V_a, t_a, d_a, D_i, d_h) \quad (3.41)$$

3.7.2 Heat balance

The ventilation rate is a parameter that depends on the size of opening and number of such openings. The integrated housing unit is made up of very large opening or large permeability; hence the ventilation parameter can only be determined by empirical equation of heat balance by Peterson *et al.* (1998);

$$S = AU\Delta t + Vc\Delta t \quad (3.42)$$

where A is the surface area of the husbandry, m^2 , U is the heat transmission coefficient for the building surfaces, $W/m^2 \text{ } ^\circ K$, Δt is the temperature difference between indoors and outdoors, $^\circ K$, V is the ventilation rate, m^3/h and c is the specific heat of air, $J/m^3 \text{ } ^\circ K$.

Temperature and relative humidity are highly coupled through non-linear thermodynamic laws as given by Daskalov *et al.* (2006): For example:

$$w = f(T, H_R, P) \quad (3.43)$$

$$w = 0.62198 P_{ws}(T) HR (P - P_{ws}(T) H_R)^{-1} \quad (3.44)$$

where: w is the moisture content of air in $g[H_2O] \text{ } kg^{-1}[\text{dry air}]$; T is the air temperature in K ; H_R is the relative humidity in %; P is the atmosphere pressure in kPa ; and P_{ws} is the saturation pressure of water vapour in kPa . This thermodynamic equation can be used to convert relative humidity to absolute water content. The relation between saturation pressure of water vapour

P_{ws} and temperature T can be evaluated by the following polynomial as given by Daskalov *et al* (2006):

$$\ln(P_{ws}) = \beta_1/T + \beta_2 + \beta_3 T + \beta_4 T^2 + \beta_5 T^3 + \beta_6 T^4 + \beta_7 \ln(T) \quad (3.45)$$

where the values of the coefficients $\beta_1 - \beta_7$ are given by Albright (1990) as:

$$\begin{aligned} \beta_1 &= -5.8002 \times 10^3; \beta_2 = 1.3915; \beta_3 = -48.6402 \times 10^{-3}; \beta_4 = 41.7648 \times 10^{-6}; \beta_5 = -14.4521 \times 10^{-9}; \\ \beta_6 &= 0.00; \text{ and } \beta_7 = 6.5460. \end{aligned}$$

For given environmental conditions, that is, given temperature T and absolute humidity w , the specific enthalpy h_0 in kJ kg^{-1} [dry air] is given by (Albright, 1990):

$$h_0 = 1.006T + w(2501 + 1.805T) \quad (3.46)$$

3.7.3 Moisture balance

The ventilation rate can be calculated by a humidity balance given by Peterson *et al.* (1998):

$$L = V\Delta H k \text{ or}$$

$$V = \frac{L}{\Delta H k} \quad (3.47)$$

where ΔH is the difference in water content between indoor and outdoor air, kg/m^3 . This equation shows in a similar way to equation (3.42) that the calculated ventilation will decrease if ΔH is increased and k is a constant.

3.7.4 Ventilation Rate

Ventilation is a parameter that cannot be easily measured in an agricultural building because it depends on size of openings and number of such openings. For this study, the size of opening is very large and therefore the ventilation rate was estimated from the balance of heat and moisture and the comparison between the heat and moisture for the estimation of ventilation rate was carried out through selection by iteration of the value of k (eq 3.47) using the Levenberg-Marquardt method (Marquardt, 1963), which allows the heat and moisture balances to give the same ventilation rate.

4.0 RESULTS AND DISCUSSION

4.1 Fish growth

Growth performance of catfish fed on varying levels of poultry dropping and concentrate feed is shown in Table 4.1. Weight gain (WG) was greatest in the Tank 4 and least in Tank 3. The average growth rate and specific growth rate data followed the same trend. Weight gain, ADG and SGR decreased linearly as the dropping levels increased. Maximum average weight gain of 553.05 g recorded in Tank 1 agreed with the findings of Pongsuwan and Sittimuk, 1989.

When the growth indices data obtained from the tanks were compared with the control, they were all significant at 5% probability levels. The general growth of the fish in the various Tanks is as shown in Figure 4.1. It could be observed from the Figure that the fish growth was an increasing rate of 10.85 g/week up to the 15th week after stocking. Thereafter, the growth was at a constant rate of 86.8g/week up to the 20th week after stocking and then there was growth at a decreasing rate of 136.56 g/week up to harvest period as shown in Figure 4.2. In Tank 2, the growth was at increasing rate of 7.47 g/week up to 8th week. Thereafter, the growth was at a constant rate of 24.88 g/week to 16th week and decreasing rate of 42.75 g/week to harvest.

The same trend was observed in Tank 3 but the growth was at an increasing rate of 8.06 g/week up to the 4th week and constant rate of 10.89 g/week to the 16th week. Thereafter, there was growth at a decreasing rate of 32.36 g/week to harvest. Tank 4 which was the control showed a different trend in the development of the fish, there was a growth at an increasing rate of 12.90 g up to the 18th week after stocking. Thereafter there was a growth at a decreasing rate of 147.22 g/week to harvest period as shown in Figure.4.2.

Table 4.1: Growth performance of *Clarias gariepinus* fed with broilers droppings and fish feed in an integrated poultry/fish aquaculture. Values ($\pm$ SEM) are means from duplicate tanks.

Parameters	Initial body weight (g)	Final body weight (g)	Weight gain (g)	ADG (g/day)	SGR (%/day)
T1	19.4 $\pm$ 4.45	572.45 $\pm$ 3.45	553.05 $\pm$ 6.00	3.04 $\pm$ 0.03	1.87 $\pm$ 0.09
T2	20.28 $\pm$ 4.10	383.83 $\pm$ 4.45	373.55 $\pm$ 6.60	2.00 $\pm$ 0.04	1.62 $\pm$ 0.09
T3	19.88 $\pm$ 5.70	279.75 $\pm$ 5.15	260.90 $\pm$ 9.55	1.44 $\pm$ 0.05	1.47 $\pm$ 0.16
T4	20.78 $\pm$ 4.05	1064.88 $\pm$ 5.00	1044.08 $\pm$ 9.40	5.74 $\pm$ 0.05	2.17 $\pm$ 0.12
Statistical significance (LSD)	NS	*	*	*	*

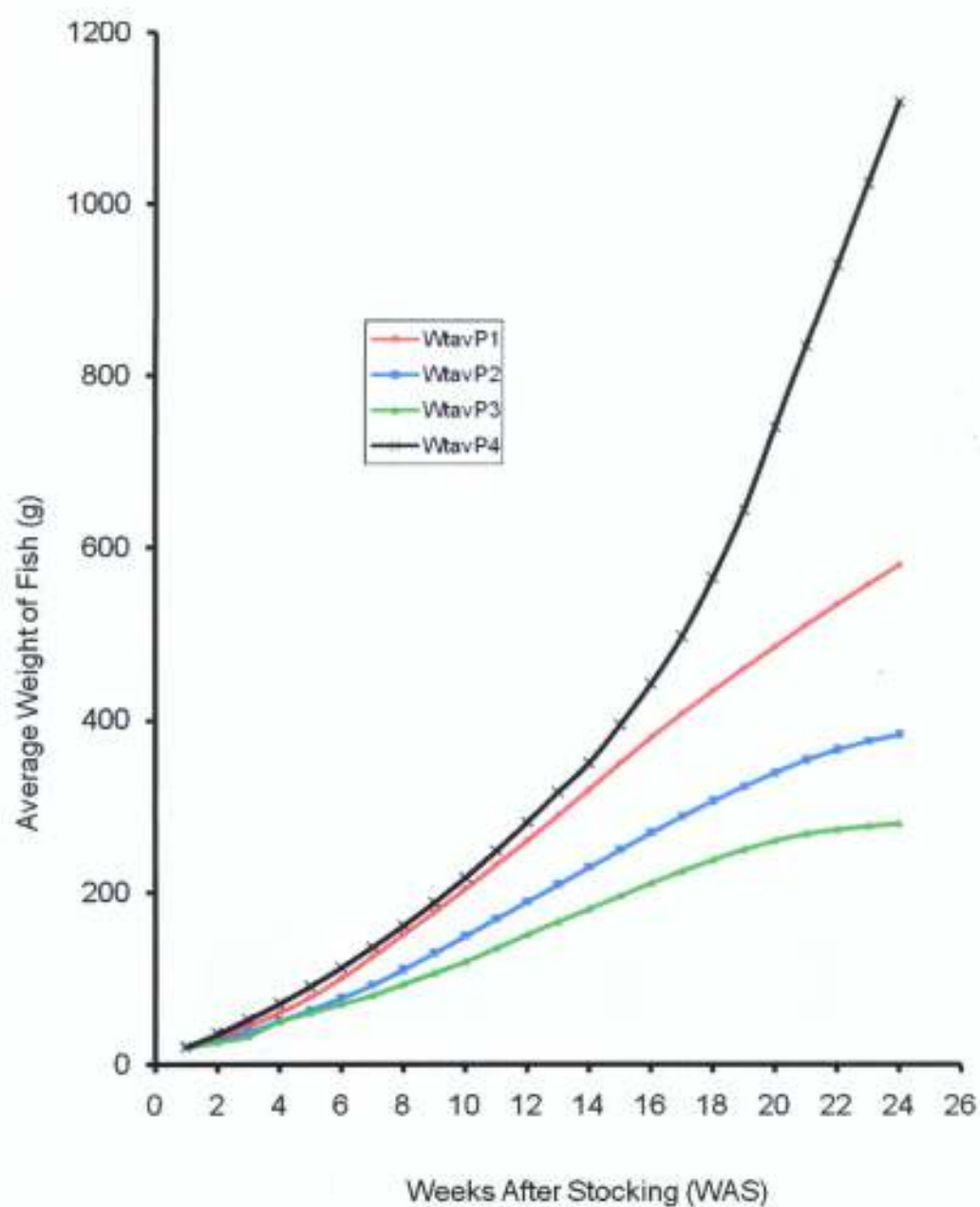


Fig. 4.1: Relationship between weight gain in catfish fed with poultry droppings and commercial feed

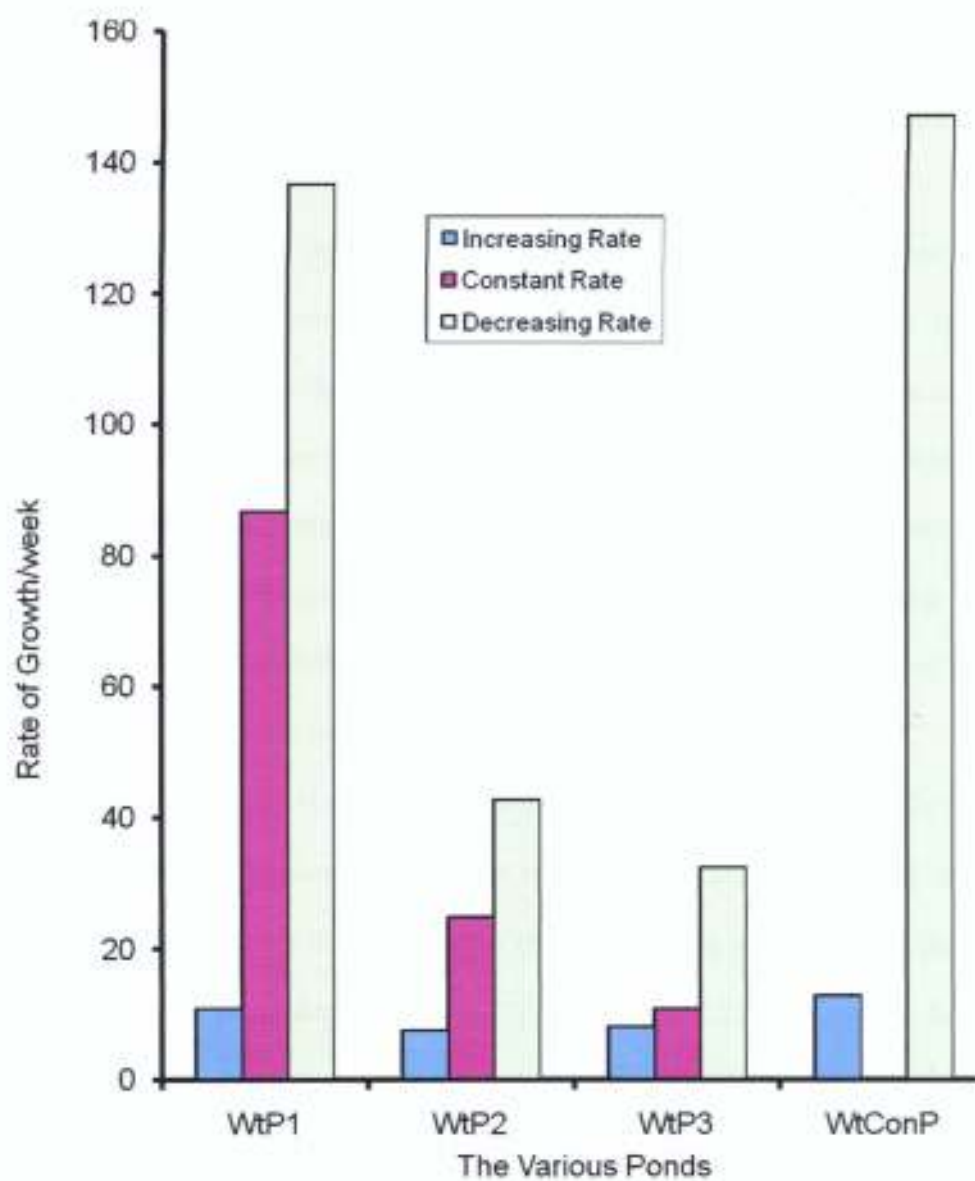


Fig. 4.2: Comparison of the Fish Growth Rate/Week in the Various Tanks

However an analysis of the variance (ANOVA) of the collected data showed that there was no significant difference in the weight of the fish in the various ponds 6 weeks after stocking as shown in Appendix A8 ($F_{\text{critical}} > F_{\text{calculated}}$ at 0.05 level). From 12 weeks after stocking to harvesting, there was a significant difference in the weight of the fish in the various ponds as shown in Appendix A9 ($F_{\text{critical}} < F_{\text{calculated}}$ at 0.05 level).

The growth of fish in Tank 1 and Control Tank showed a similar trend until the 16th week after stocking and this observation suggests that the droppings from the birds were having adverse reaction on the development of the fish and this might be that average weight gained by the bird was more than that of the fish. This observation implied that the bird must be changed at 16th weeks after stocking. It is obvious from Figure 4.1 and Figure 4.2 that the fish in Tank 1 fed with droppings from only one bird compared favourably with Tank 4 which was the control. This was followed by the fish in Tank 2 fed from droppings of two birds and lastly the fish in Tank 3 fed with droppings of three birds.

A regression analysis was carried out to predict the weight of fish in the various ponds when compared with the control pond. The regression of Tank 1 on Tank 4 is as shown in figure.4.3 which showed a high correlation ($R^2=0.9985$) and polynomial of the third degree best described the relationship i.e $y = 3E-07x^3 - 0.001x^2 + 1.2585x - 20.261$. A regression of Tank 2 on Tank 4 showed an equation $y = 2E-07x^3 - 0.0007x^2 + 0.8721x - 7.1101$ with a correlation of 0.99 ($R^2=0.99$) while the regression of Tank 3 on Tank 4 was fitted with the polynomial equation $y = 1E-07x^3 - 0.0005x^2 + 0.6725x + 1.8387$ with high correlation ($R^2 = 0.9988$). Mortality rate of 20% was recorded in Tank3 during the experiment. However, no mortality rate was recorded for Tank 2 and Tank 1. The experiment did not allow for sorting of the fish as development progressed hence losses as a result of cannibalism or death of about 15% was recorded in all the ponds

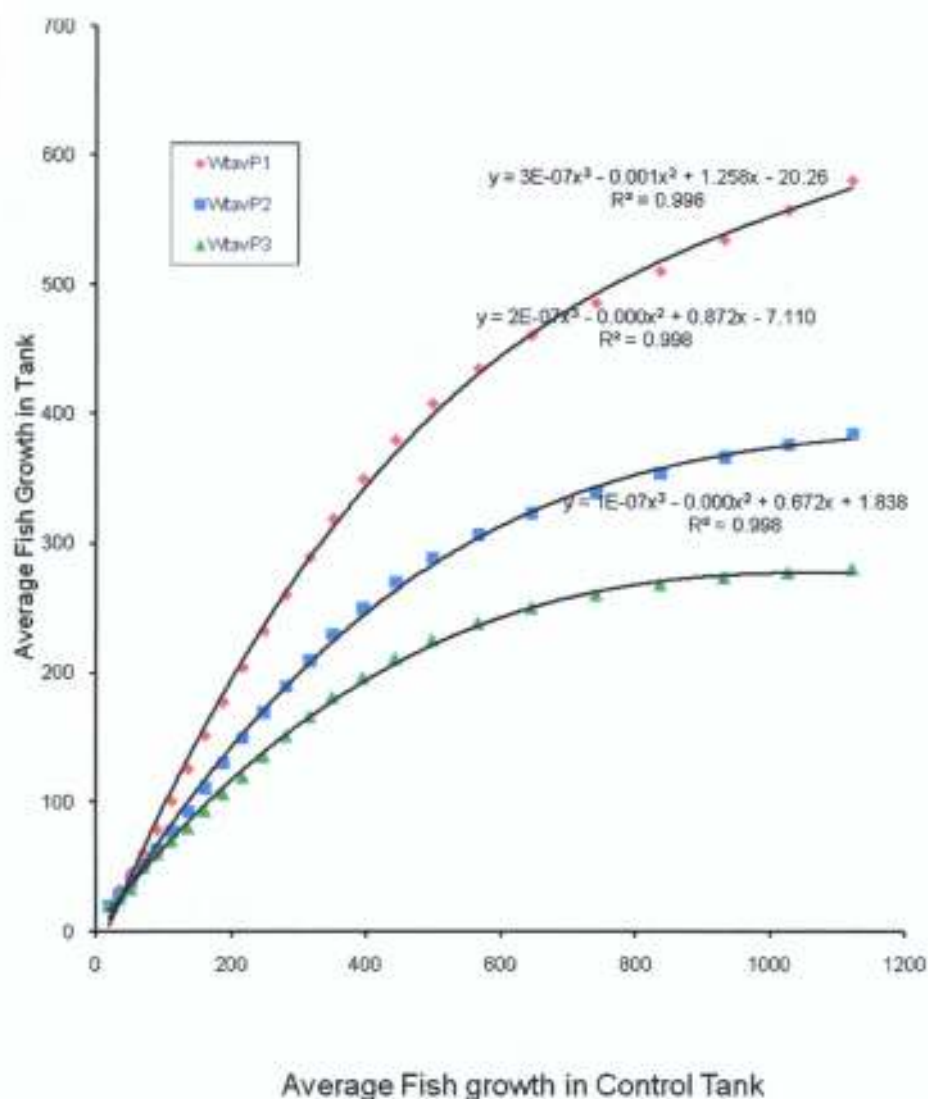


Fig. 4.3: Regression of Fish Growth in Tanks on the fish growth in the Control Tank

4.2 Water Quality in Tanks

4.2.1 pH level in the Tanks

The pH value of the water in the various tanks through out the experiment varied between 5.9 and 7.0 in Tanks 1, 6.3 to 7.7 in Tank 2 and 6.6 to 7.8 in Tank 3. The fluctuations in the values of the pH in the tanks is shown in Figure 4.4. However the values of pH recorded in the tanks were within the acceptable limit necessary for optimum growth of cat fish. The value of pH recorded in the control Tank was slightly higher than that obtained in tank 1.

4.2.2 Turbidity level in the tanks

The turbidity level in the various tank water throughout the period of the experiment is shown in Figure 4.5. The turbidity of the water increased during the experiment. Highest value of turbidity was recorded in Tank 3, followed by tank 2 and tank 1. The least value of turbidity was recorded in control treatment tank. This trend must have been as a result of the increased quantity of droppings into the tanks. A linear relationship was established between turbidity of water in the tanks and time after stocking which showed a high correlation ranging between 0.979 and 0.99 as shown in Figure 4.5.

4.2.3 Dissolved oxygen level in the ponds

The total dissolved oxygen (DO) level in the various tanks throughout the experiment is shown in Figure 4.6. The value decreased significantly towards the end of the experiment in all the ponds. This development might be as result of increase in the weight of the birds bringing about an increase in the quantity of droppings. The poultry droppings is an organic material which has high BOD and capable of utilising the oxygen in the water. Dissolved oxygen depletion was highest in tank 3 followed by tank 2 and tank 1 and least oxygen depletion was recorded in control treatment tank.

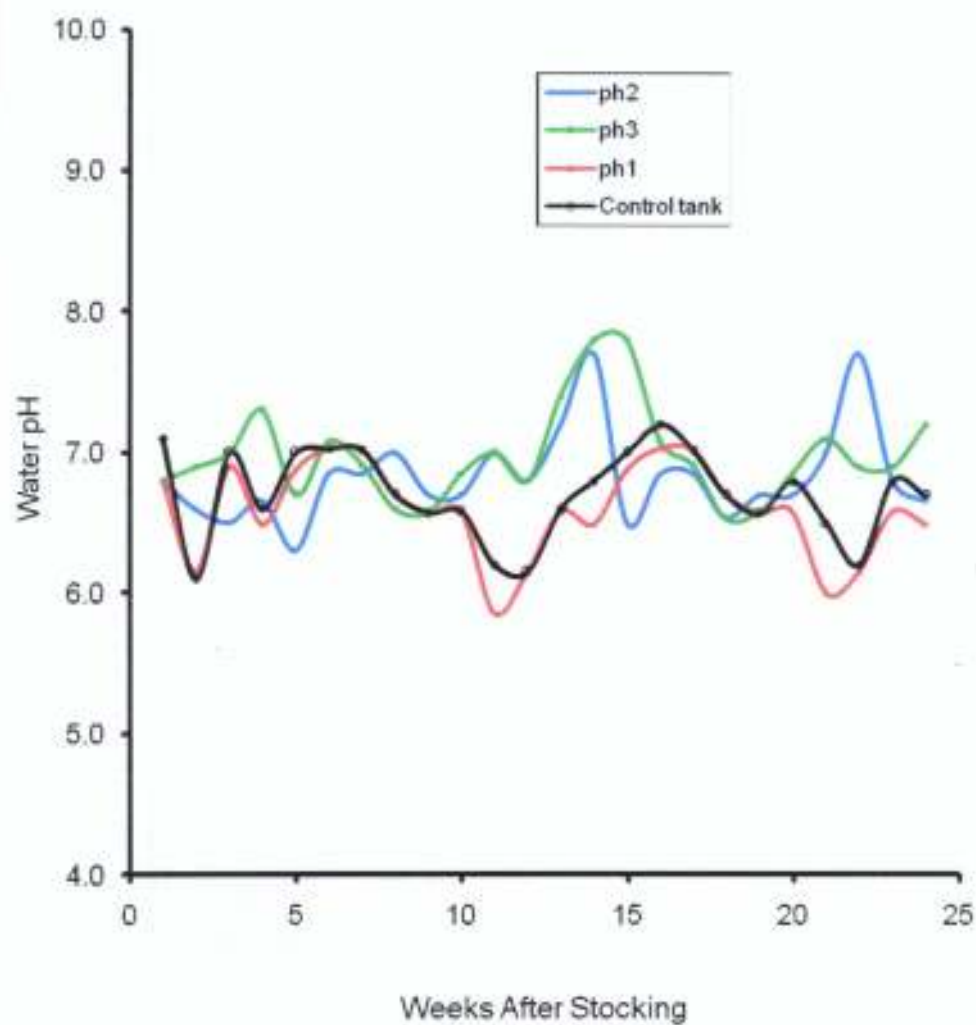


Fig 4.4. pH Values of water in the various tanks

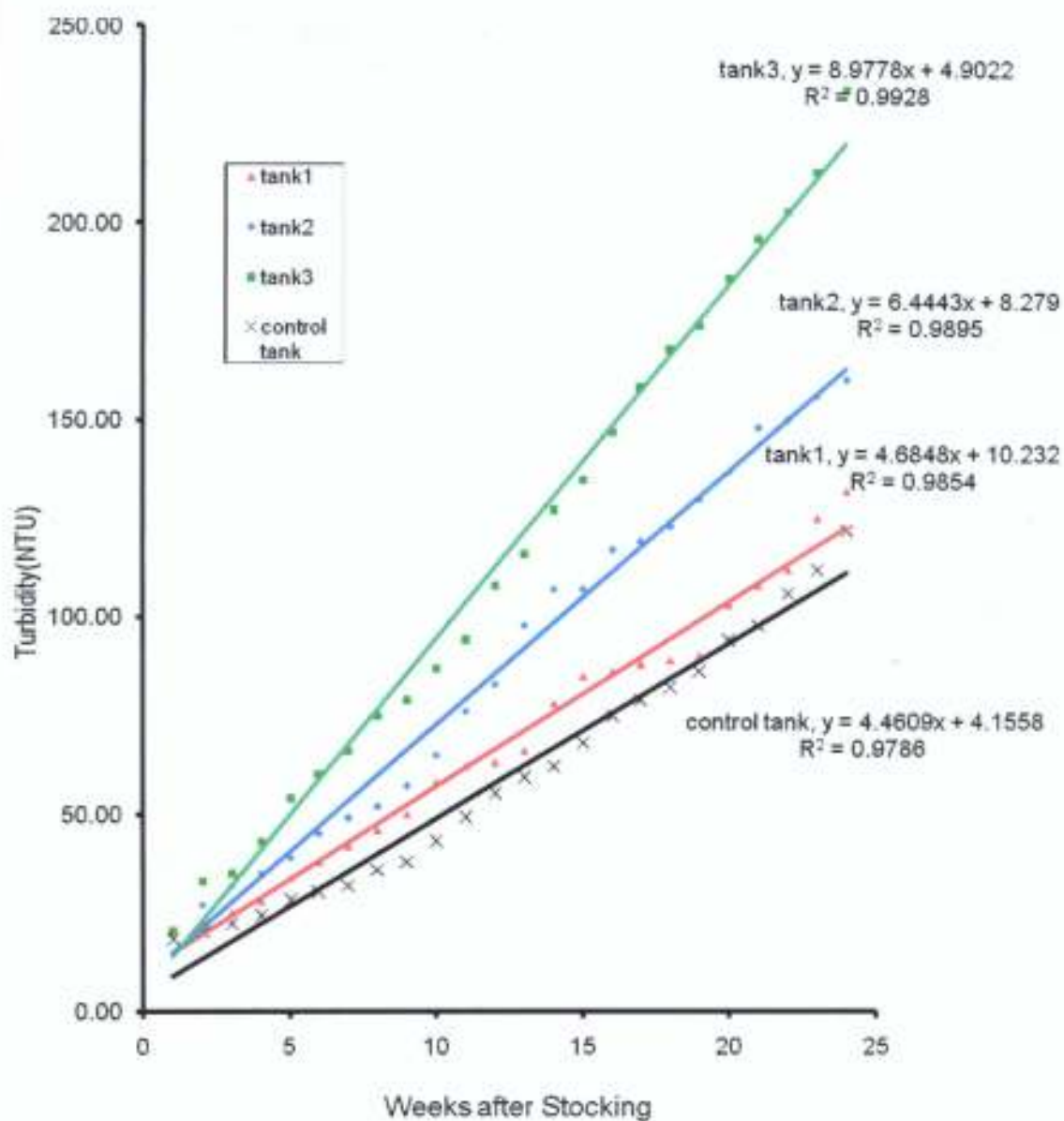


Fig.4.5 :Turbidity levels in the various tanks

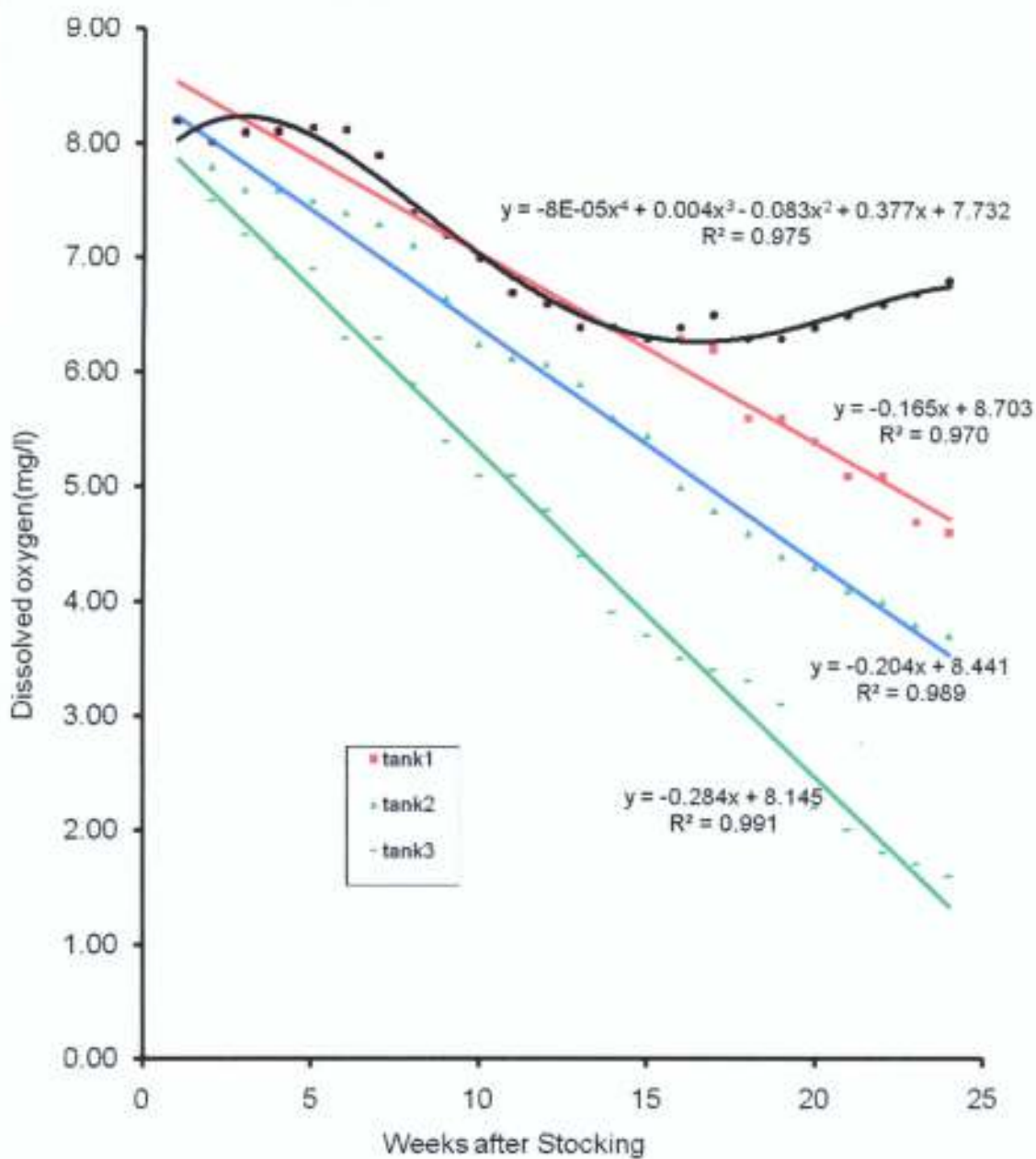


Fig.4.6: Dissolved oxygen in the various tanks

When compared with the tolerable (DO) standard level, the values of dissolved oxygen in tanks 1 and 2 were within the limit suitable for catfish culture (Viveen et.al. 1986) while that recorded in tank 3 towards the end of the experiment was below the standard required for effective catfish production. This must have been responsible for the retarded growth of fish in the tank.

4.2.4 Chemical oxygen demand (COD) level in the tanks

The chemical oxygen demand (COD) increased in all the tanks from stocking to the end of the experiment as shown in Figure.4.7. The COD level recorded in tank 3 was the highest. This was expected because of the quantity of droppings into the pond which increased with age of the birds. Also as expected, the COD values (Figure 4.7) in the tanks were greater than the BOD values in Figure 4.10 because more compounds could be oxidised chemically than could be oxidised biologically. However, the value of COD recorded in control tank was the least.

4.2.5 Conductivity level in the Tanks

Conductivity values ranged from 0.42 to 0.82 μscm^{-1} throughout the period of experiment as shown in Figure 4.8. It was observed that the conductivity level was unstable through out the period of the experiment. The highest value of conductivity was noticed in tank 3 and the least in control tank. The high value of conductivity might be connected with the droppings into the tanks.

4.2.6 Variation in colour of water in the tanks

The colour of water in the various tanks is as shown in Figure 4.9. As expected, the highest value of colour of water was recorded in Tank 3 and the least in control Tank.

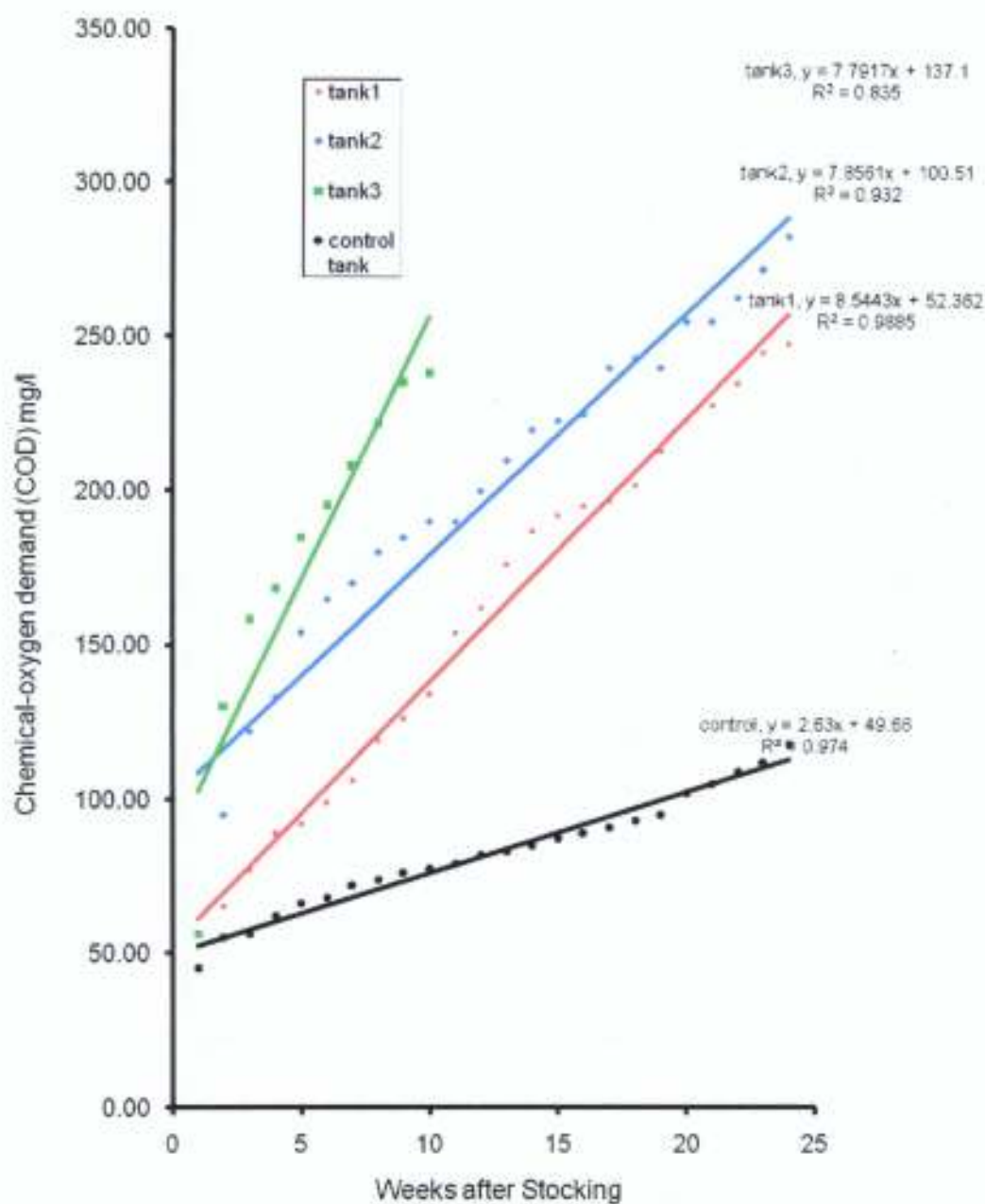


Fig 4.7: Chemical Oxygen Demand (COD) in the tank water

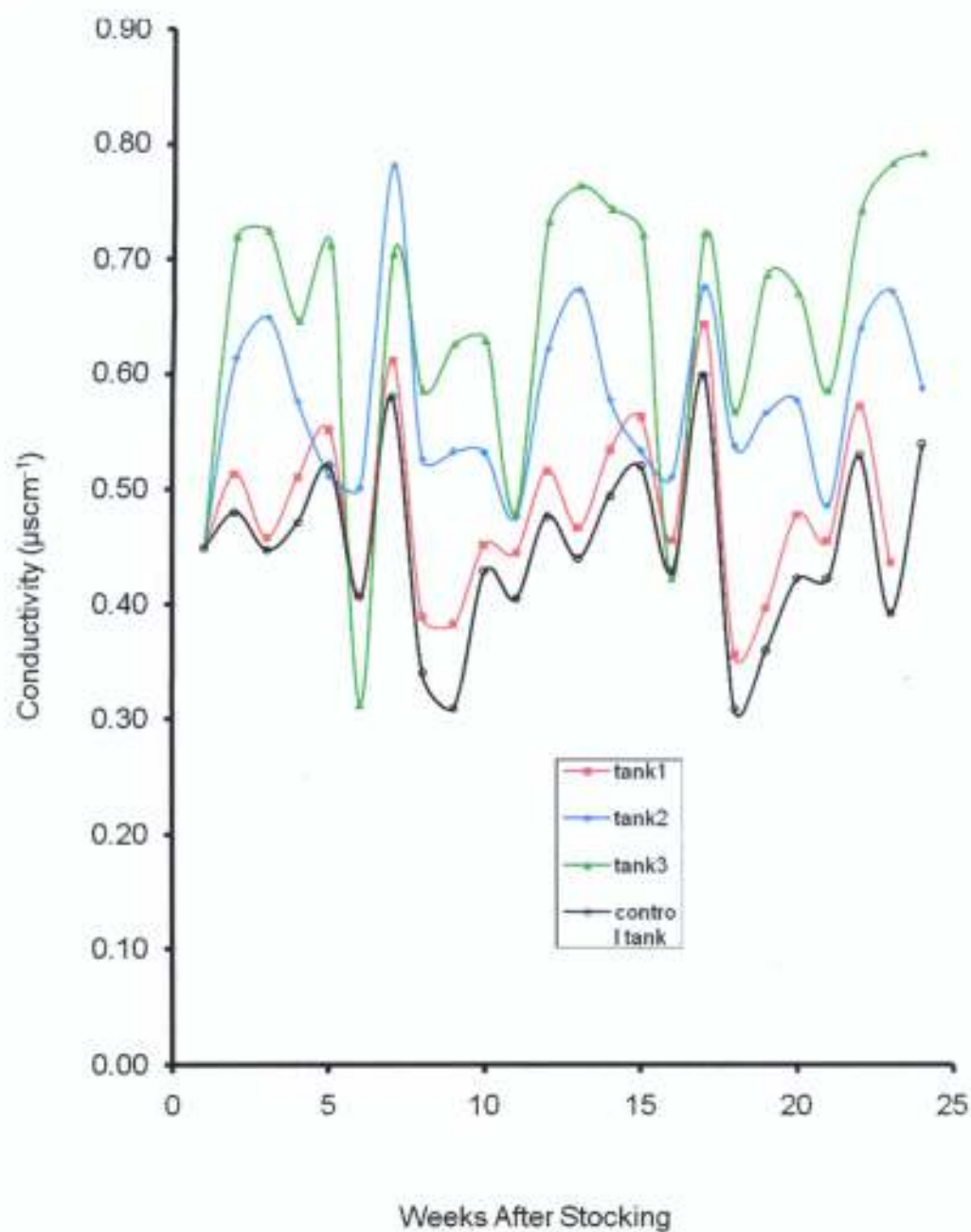


Fig.4.8: Conductivity of water in the tanks

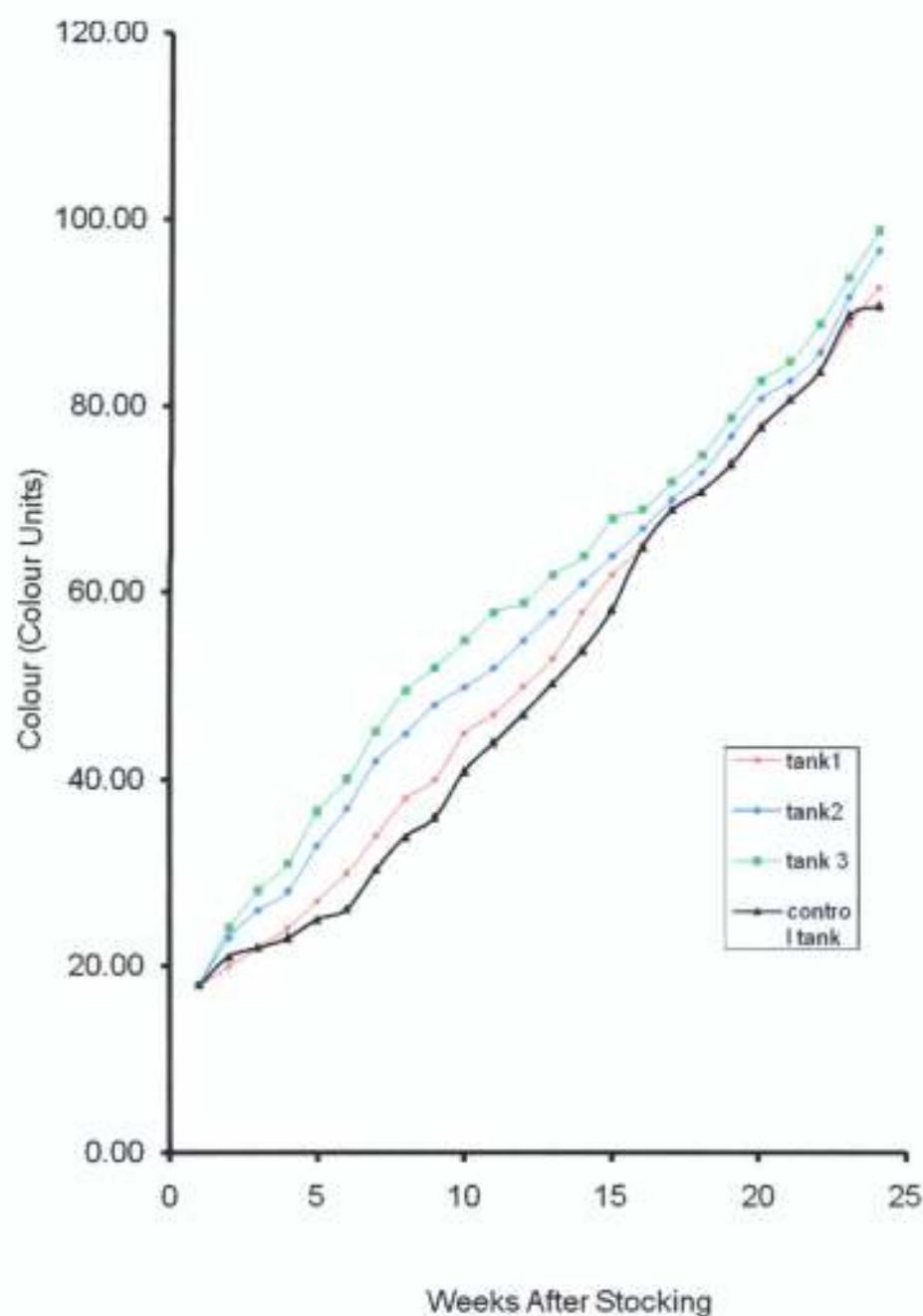


Fig.4.9: Colour of water in the tanks

The increased colour change in the tanks must have been due to the quantity of droppings from the poultry birds and the age of the birds.

4.2.7 Bio-chemical oxygen demand (BOD) level in the tanks

The variation in the BOD level in the various tanks throughout the period of the experiment is shown in Figure 4.10. As expected, highest value of BOD was recorded in Tank 3 and least value was recorded in tank 1. The introduction of oxygen – demanding material like poultry droppings into tank would expectedly caused the depletion of the dissolved oxygen in the water. This might pose a threat or affect the growth of the fish if the concentration falls below a critical point. A linear relationship was established between the BOD level and weeks after stocking with a high correlation which ranged between 0.92 and 0.993 as shown in Figure 4.10.

4.2.8 Chloride level in the tanks

Chloride level in the various tanks during the period of experiment is shown in Figure 4.11. The highest chloride level was observed in tank 3 while the least was recorded in tank 1. The value of chloride recorded all the tanks ranged between 0.00 -0.02 mg/l. The chloride level was within the value specified by Boyd (1979) considered suitable for the growth of catfish (not > 0.02 mg/l).

4.3 Growth of the Birds

The birds recorded an increasing weight gain throughout the period of the study. The average weight gain during stocking to the end of the study varied from 0.7kg to about 6kg. There was no significant difference at 5% level in the average weight of the birds in the various cages as shown in the ANOVA table shown in Table 4.1 and Fig.4.12 and this

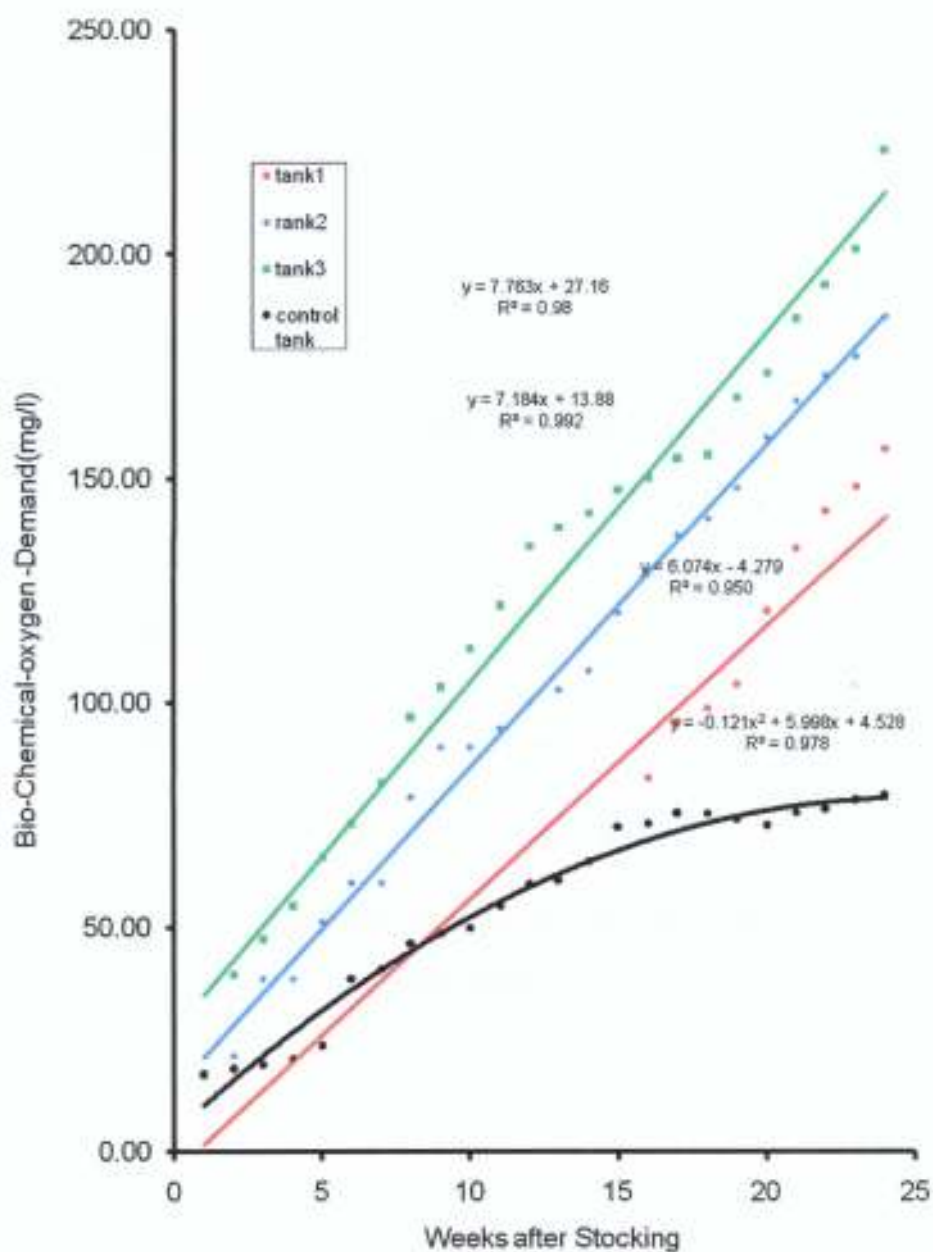


Fig.4.10: Bio-Chemical-Oxygen-Demand of water in the tanks

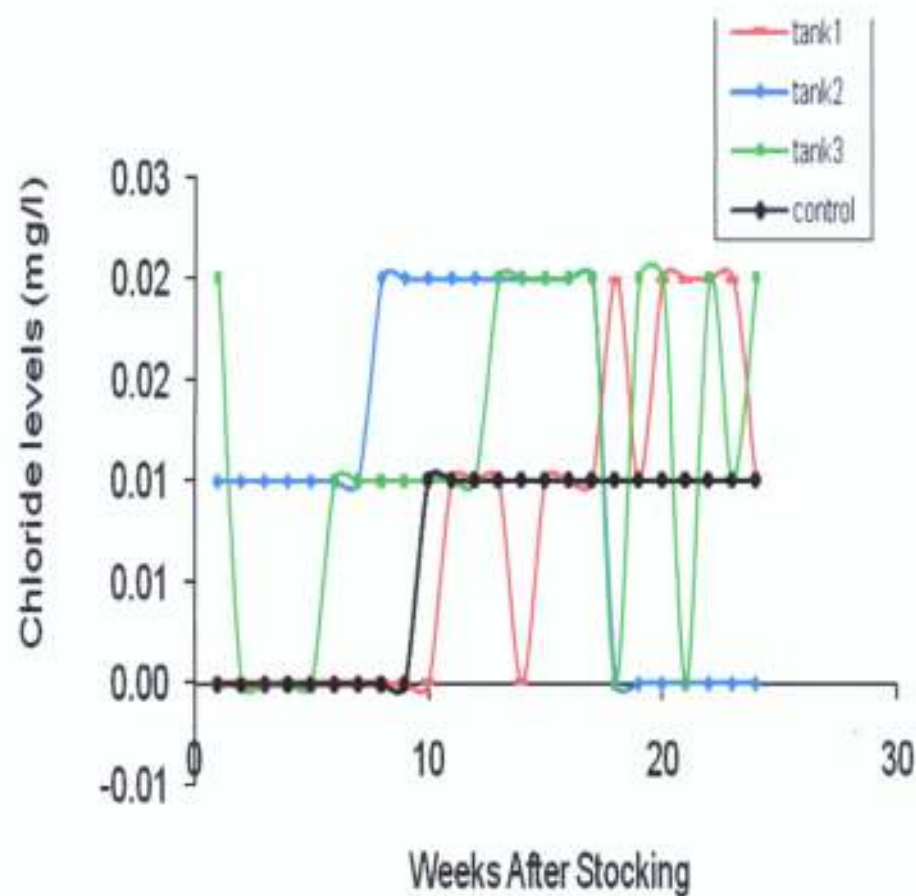


Fig.4.11: Relationship between chloride levels in the various tanks

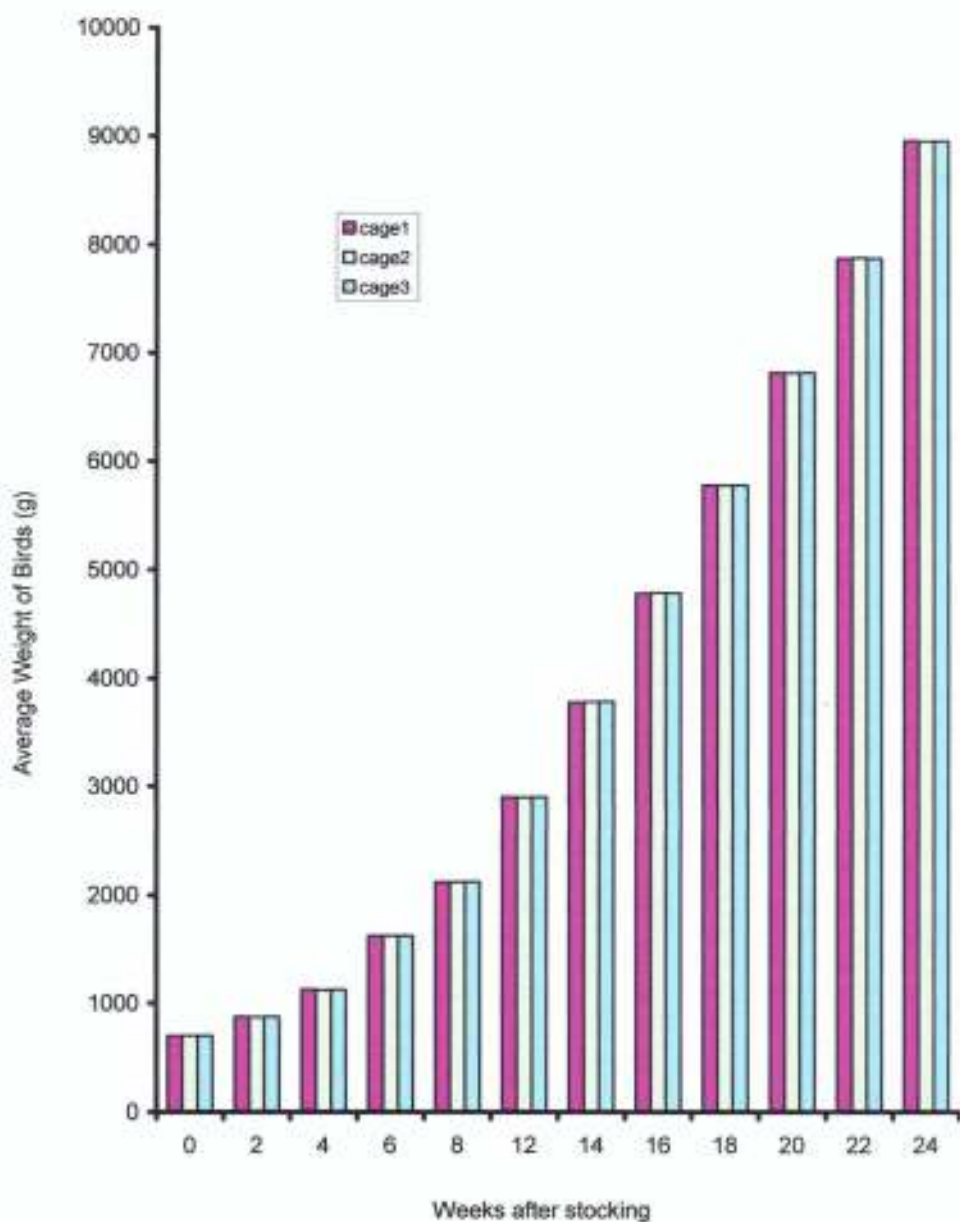


Fig.4.12: Relationship between the average weight of birds and weeks after Stocking

implied that the growth of birds in the cages was equal throughout the period of the study. No mortality was recorded throughout the period of study for the broilers and this confirmed that the environmental conditions of the housing unit were suitable for poultry production. A log-log plot of the weight of birds and time is shown in Fig. 4.13. This relationship, $\text{mass} \propto \text{time}^n$ where n is 1.66, relates the growth of weight of birds as a power of time and similar to the observations of Kettlewell, P. J. and Moran, P. (1992) and Aerts et al. (2000).

Table 4.2. Analysis of Variance (ANOVA) of Weight of Birds in Cages

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
cage1	12	47388	3949	8254983
cage2	12	47385	3948.75	8258748
cage3	12	47395	3949.583	8255381

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	4.388889	2	2.194444	2.66E-07	1	3.284918
Within Groups	2.72E+08	33	8256371			
Total	2.72E+08	35				

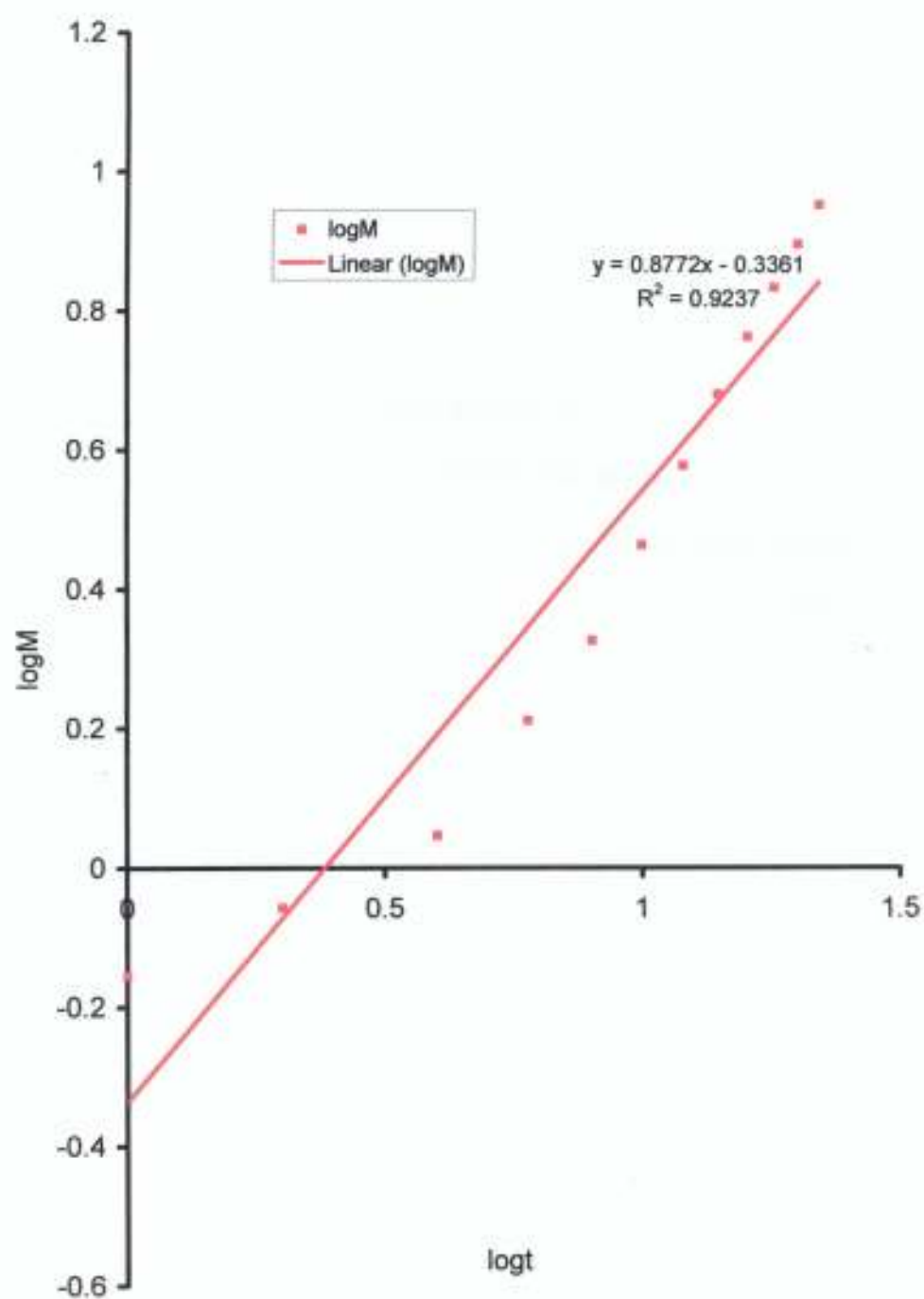


Fig. 4.13 LogM versus Logt

4.4 Monitoring of Environmental Parameters

4.4.1 Relative humidity variations

The relative humidity within and outside the poultry house unit in the morning (6.00hrs - 8.00hrs), afternoon (13.00-15.00hrs) and evening (17.00hrs- 19.00hrs) was plotted against the days after stocking as shown in Fig. 4.14, 4.15, and 4.16. The relative humidity within the integrated aquaculture in most cases was higher than that of the outside.

In the morning (6.00hrs -8.00hrs) there was a marked difference between the indoor and outdoor relative humidity. The relative humidity outside varied between 77.7% and 96.8% while the relative humidity inside varied between 83.6% and 98.8%. The increase in relative humidity resulted from evaporation of water from the tank surface. This is a very high relative humidity and could influence the growth of disease causing micro-organisms, which could adversely affect the well being of the birds. However, no incidence of disease was recorded throughout the period of the experiment because of lower temperature and increased management practices. Since a battery cage system was used for the birds, it was not possible for the birds to contaminate the feed and the water.

In the afternoon (13.00-15.00hrs), the relative humidity outside and inside the building followed the same pattern as in the morning. This might be as a result of an increase in wind movement. The relative humidity inside varies between 43.2% and 83.5% while that of the outside varied between 40% and 80.7% as shown in Figure 4.15.

In the evening (17.00-19.00hrs), the pattern was not different from that of the morning, which implied that the relative humidity conditions inside, the building was slightly higher than that of outside. The relative humidity inside varied from 57% to 89.3% while that of outside varies from 56.6% to 87.6%, which was normal and within the comfort zone of broilers as stated by Seedorf, et al (1998) as shown in Figure 4.16.

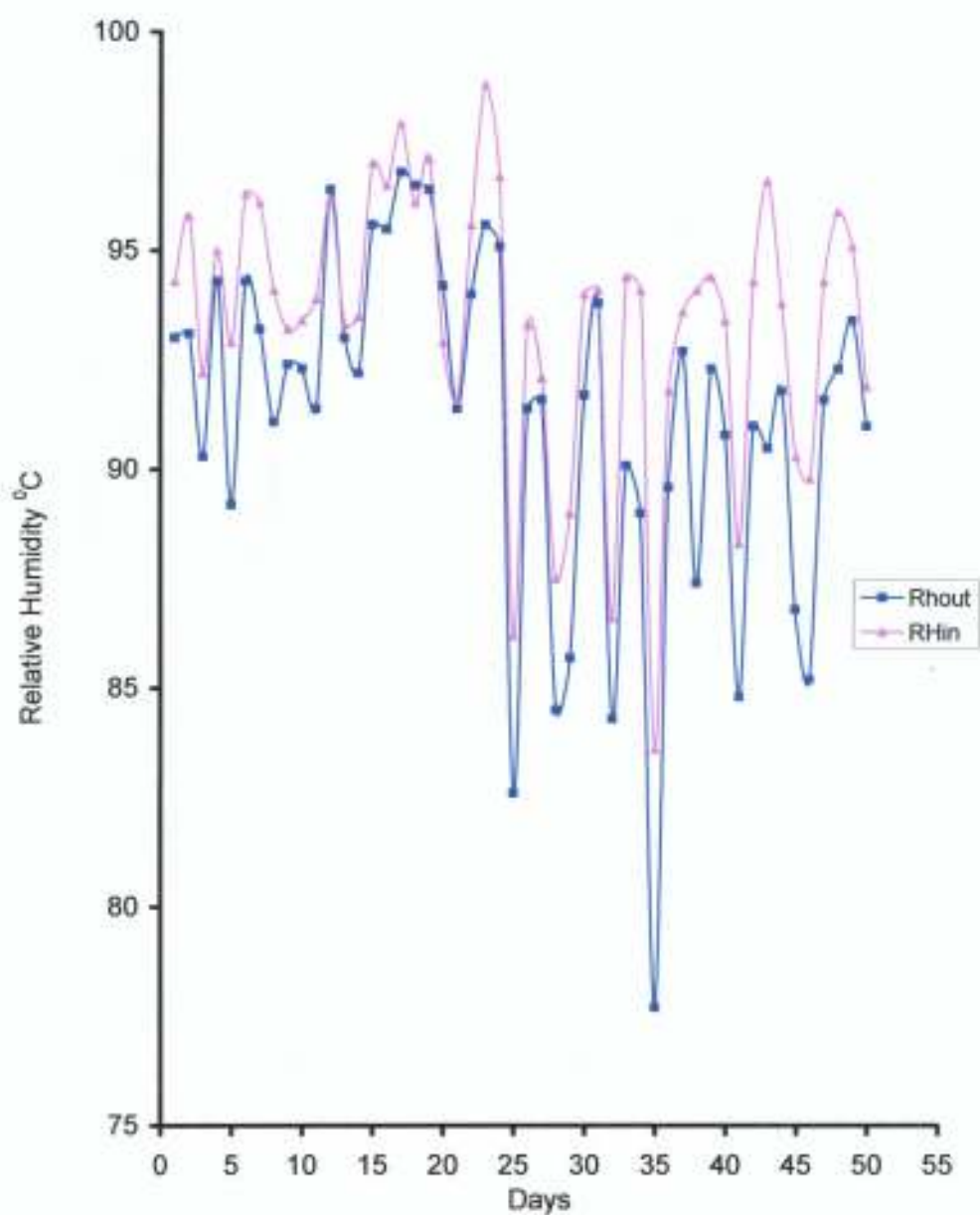


Fig.4.14: Relative Humidity Outside and Inside the Building against Days in the Morning

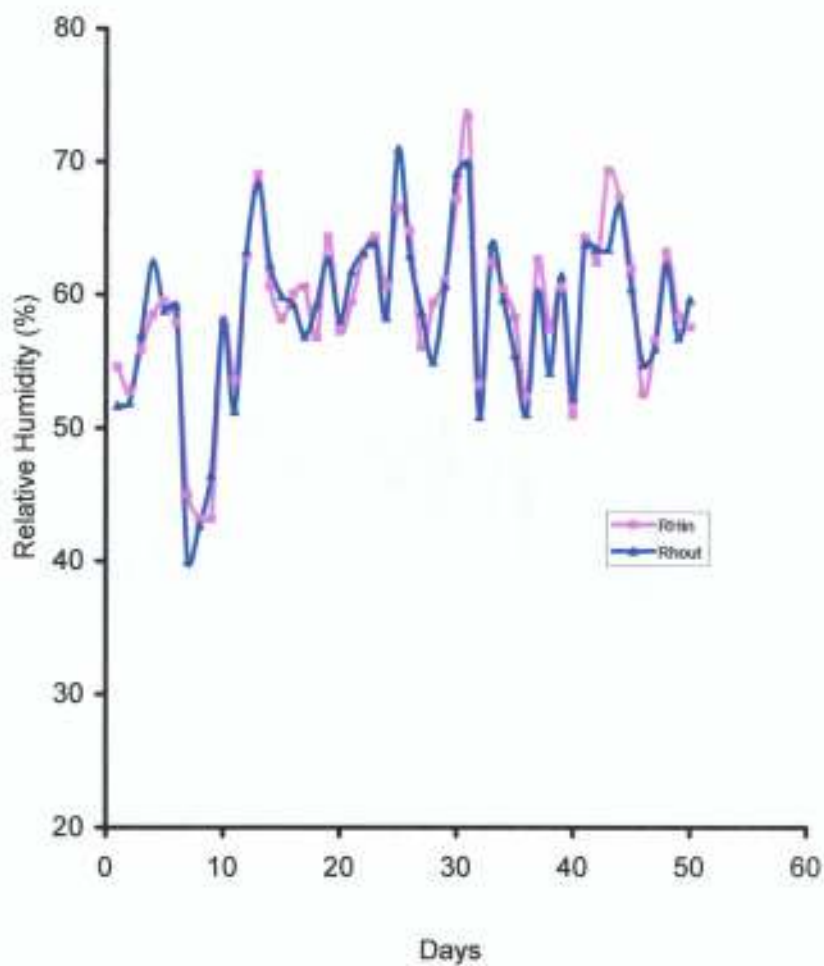


Fig. 4.15: Relationship between relative humidity inside and outside in the Afternoon

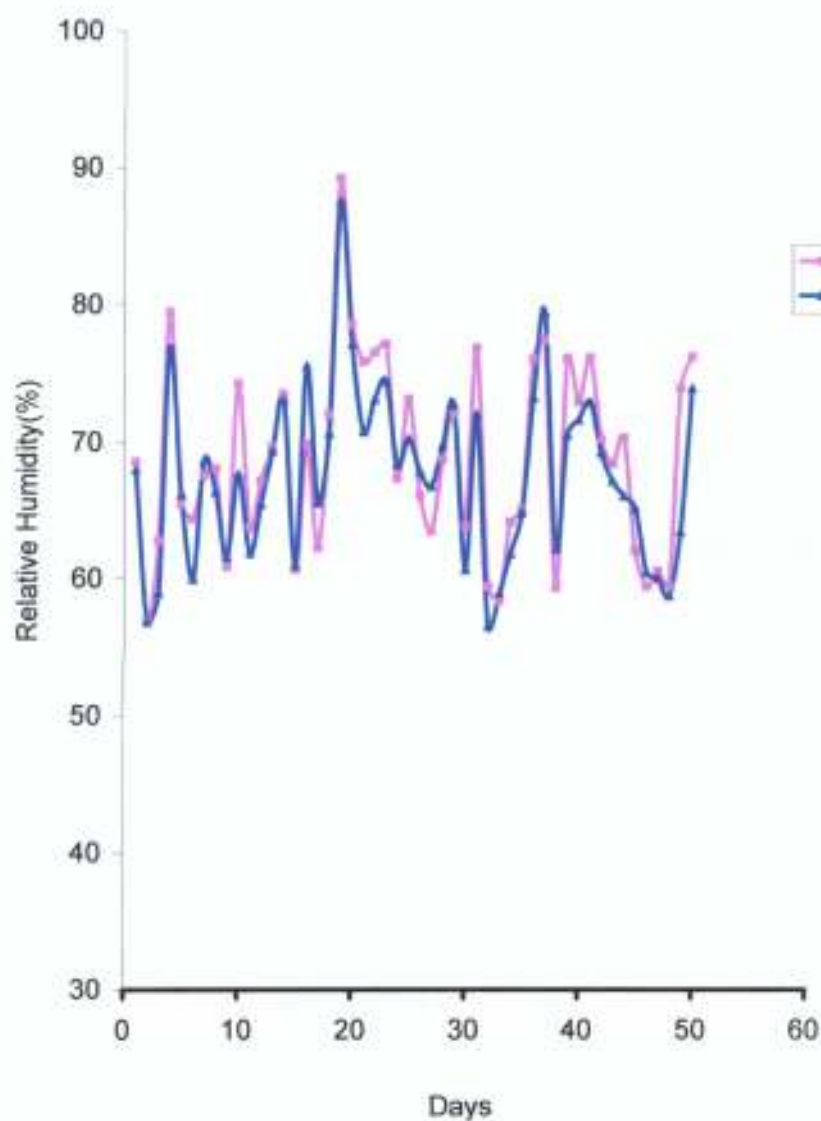


Fig. 4.16: Relationship between relative humidity inside and outside the building in the evening

4.4.2 Temperature variations

The indoor and outdoor temperature varied with the periods of the day. In the morning the indoor temperature was usually greater than that of outdoor temperature but in the afternoon the outdoor temperature was slightly higher than the indoor temperature. The indoor temperature in the morning (6.00 – 8.00hrs) ranged between 21.2 °C and 27.1 °C while the outdoor temperature ranged between 21.7 °C and 27.3 °C as shown in Figure 4.17. In the afternoon (13.00 -15.00hrs), the indoor temperature ranged between 26.1 °C and 34.6 °C while the outdoor temperature ranged from 26.9 °C to 36.3 °C as shown in Figure 4.18. In the evening (17.00-19.00hrs) outside and inside temperatures followed the same pattern. The outdoor temperature varied between 25.2 °C and 33 °C while the inside temperature varied between 25.2 °C and 32.7 °C. This is considered normal and within the thermo neutral or comfort zone of broilers (Van Kampen, 1997).

4.5 Modelling of Environmental Parameters

The Heat balance and moisture balance equation in equations 3.40 and 3.41 respectively which are data driven models were validated by fixing collected data into them and optimised using the Levenberg-Marquardt method (Marquardt , 1963). A computer program (Sigmaplot) was used for the validation and determination of the regression statistics. The detailed fixed data using equations 3.40 and 3.41 is as shown in table 4.2. The optimisation carried out using the Levenberg-Marquardt method showed that the value of missing constant (k) is 0.2360 and the equation of moisture balance can then be written as $V = \frac{L}{\Delta H 0.236}$.

This equation is different from that used by Pedersen *et-al* (1998) and the reason might be as a result of differences in the climate and environment of the humid tropics and temperate regions of the world.

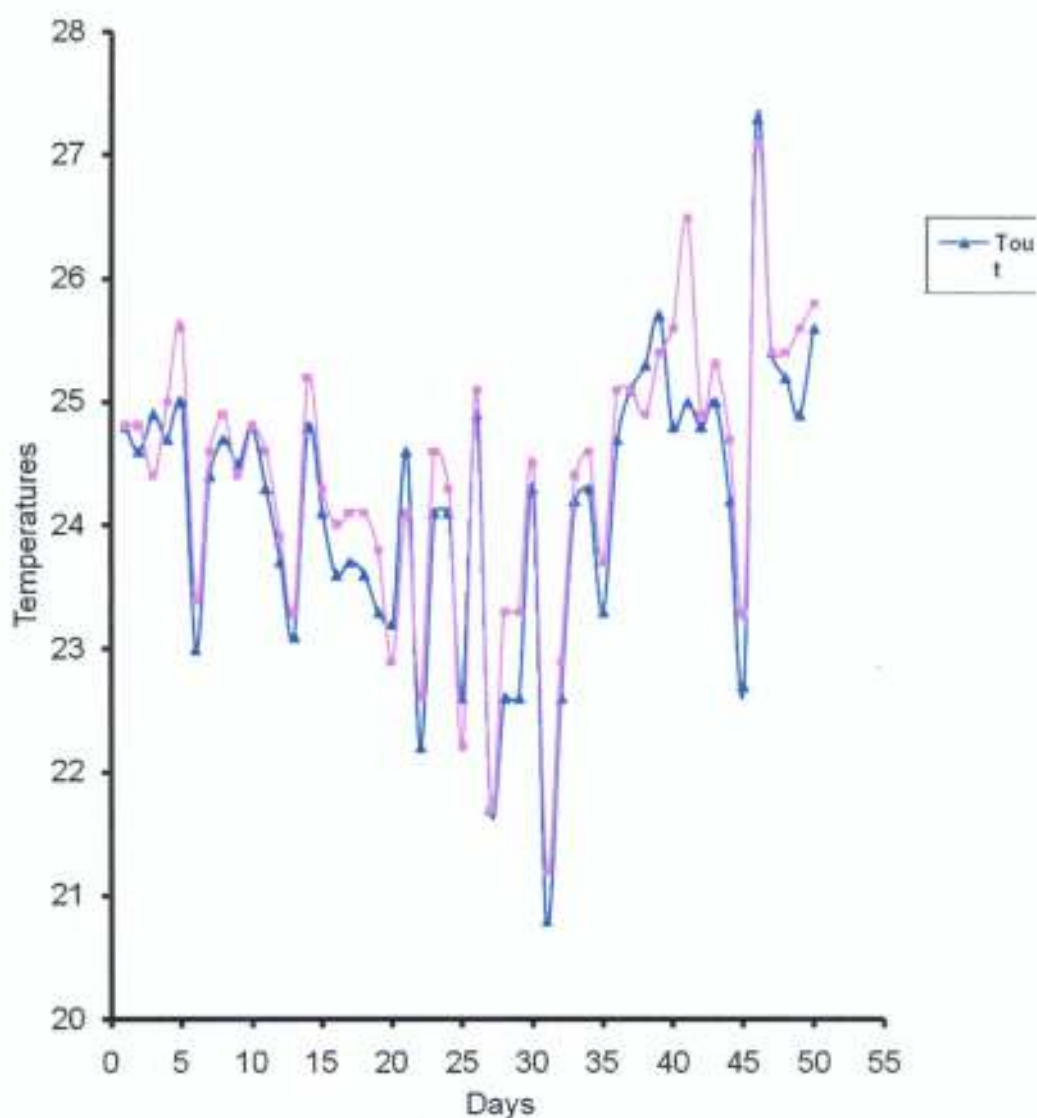


Fig. 4.17: Temperature Outside and Inside the Building in the Morning

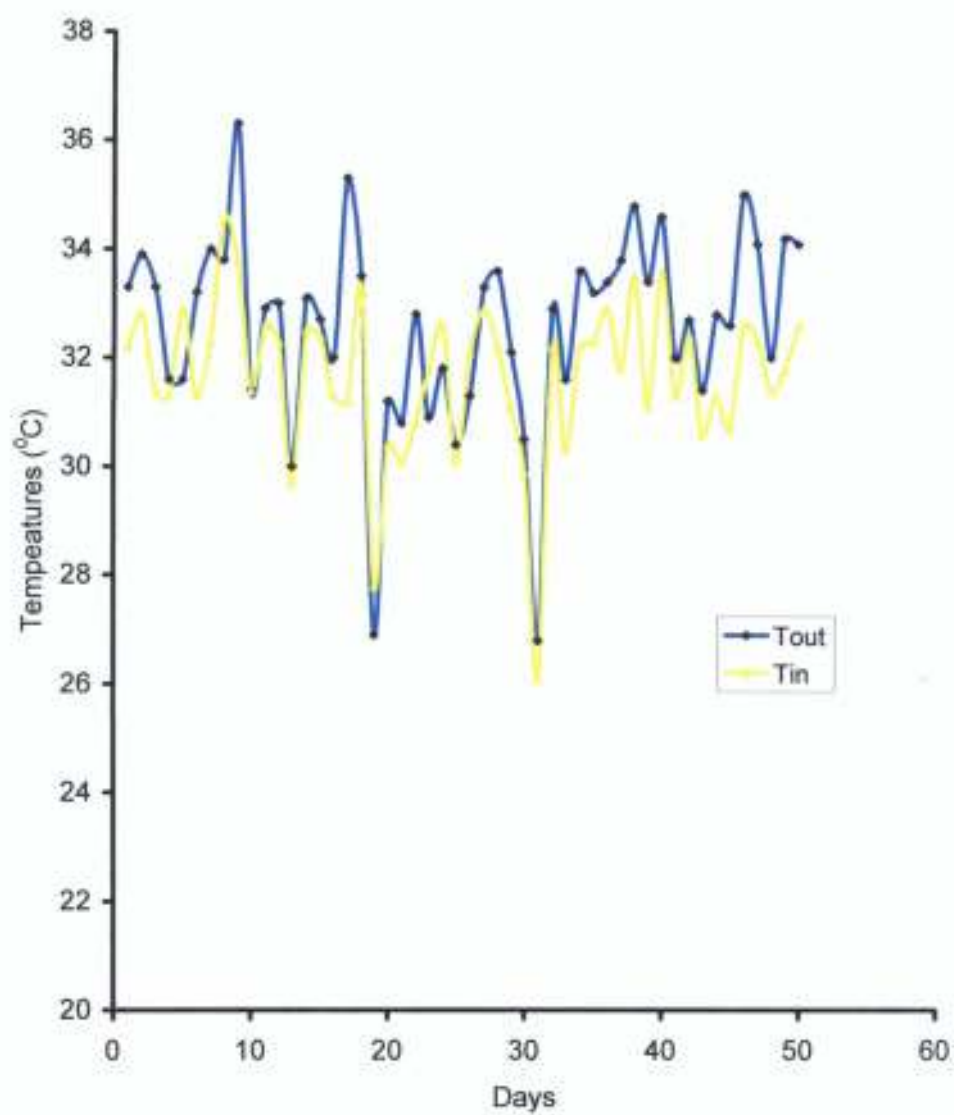


Fig.4.18: Relationship between outside and inside temperatures in the afternoon

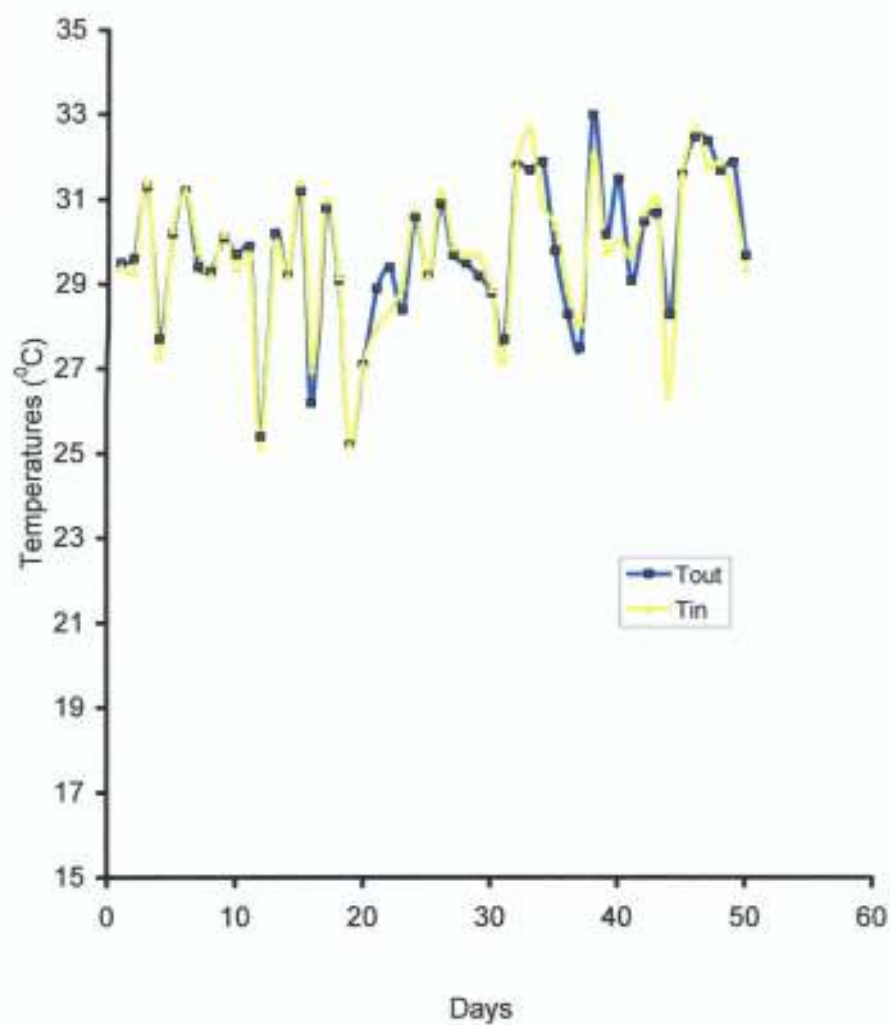


Fig.4.19: Relationship between temperatures outside and inside the building in the Evening

In total, three different sets of data were collected vis a vis morning, afternoon and evening data. The variables U and Z were put in the data matrices in the same order as in equations 3.40 and 3.41. One set was used for the identification procedures and the second, and third for simulation and validation of the identified models. Model parameters such as relative humidities inside and outside the building, air temperatures inside and outside the building, total heat produced as a result of metabolic activities of the birds and ventilation in the building were subjected to a stepwise regression analysis to determine the effect of each of the parameters on the growth and development of the birds inside the building are shown in appendices 10 -15. The combined effects of the parameters were also determined. The estimated coefficients of the model obtained are as shown in Table 4.3.

The ANOVA for the regression of weight of birds on model parameters is as shown in Table 4.4. The coefficient of determination is 0.9994 which is very high. The model describing the effect of environmental parameters on the growth and development of poultry birds in an integrated poultry/fish system may then be written as;

$$Wt = 6.2296 - 0.0748H_{Rout} + 0.06762H_{Rin} + 0.62024T_{in} - 0.84806T_{out} + 0.04704Q_T + 0.00509V_{ent} \quad (4.1)$$

The equation is valid for initial weight of birds of 0.7kg which was the initial average weight of bird used for the experiment.

Table 4.3: Validation of heat and moisture models using optimisation

RHout	Rhin	Tin	Tout	weight of birds	Q	q	S	L	V fr Temp balance	*Constant	V fr Moisture balance
40.1	55.5	32.8	33.1	0.700	5.356999	29.44573	5.276881	24.16885	6.4	0.236	6.6
42.6	60.2	32.1	32.8	0.876	6.338349	35.34472	7.762497	27.58222	6.3	0.236	6.6
53.3	64.3	31.1	31.8	1.113	7.585242	43.04091	11.77521	31.2657	11.7	0.236	12.1
60.2	63.9	31.7	31.9	1.626	10.07949	56.58829	13.57222	43.01607	50.7	0.236	49.6
53.3	63.2	31.0	31.7	2.122	12.30714	69.92673	19.437	50.48973	22.0	0.236	21.7
52.4	63.3	32.8	33.2	2.903	15.56802	85.57247	15.33519	70.23728	26.9	0.236	27.2
50.2	61.9	33.2	33.6	3.784	18.99159	103.4663	16.10686	87.35949	31.7	0.236	31.5
53.5	62.3	32.1	32.6	4.785	22.64694	126.2527	27.6284	98.62432	48.4	0.236	47.5
52.6	63.5	32.7	33.2	5.788	26.12128	143.8861	26.61728	117.2689	46.4	0.236	45.6
49.1	62.4	28.4	30.5	6.824	29.55475	173.1244	68.86013	104.2642	31.2	0.236	33.2
48.5	60.3	30.2	31.5	7.883	32.93189	189.2039	59.95054	129.2534	43.5	0.236	46.4
49.7	60.7	27.4	29.4	8.967	36.273	214.1103	93.78931	120.321	45.2	0.236	46.3

* constant got from optimization process using Marquardt, 1963

Table 4.3 : Regression Coefficients for model

Y-variate: WBIRDS

Param.	Estimate	SE	t	Prob> t
Const	6.2296	3.038	2.05	0.0955
RHOUT	-0.0748	0.038	-1.97	0.1064
RHIN	0.06762	0.055	1.23	0.2739
TIN	0.62024	0.3123	1.99	0.1038
TOUT	-0.84806	0.422	-2.01	0.1007
QT	0.04704	0.0022	21.03	0.0000
Vent	0.00509	0.0079	0.64	0.5481

Instat+ for Windows - Version 2.52

Table 4.4: ANOVA for regression of WtBIRDS on RHOUT RHIN TIN TOUT QT Vent

Source	df	SS	MS	F value	Prob>F
Regression	6	90.8427	15.14	1299.40	0.0000
Residual	5	0.058259	0.01165		
Total	11	90.9009			

R-squared = 0.9994

4.6 Validation of the Model

The validation of the estimated parameter values for the identified model was carried out by the examination of residuals. Basically, residuals are the differences between observed y-values and the corresponding fitted values. For the usual significance tests and confidence intervals derived from regression calculations to be valid, the examination of residuals should include some check on the normality of their distribution. The probability plot is shown in Figure. 4.20 and the simulated line fit plot is shown in figure 4.21. The scatter plot is very close to a straight line which implied that the residuals are approximately normally distributed.

The model leverage values (LEV) was tested to find out if the i th observation will have an undue importance in determining the regression model. This means that a high leverage indicates an unusual combination of x-values in the sense that it is different from the bulk of the observations. A commonly used rough rule for assessing leverage values is to give attention to cases where i th observation is greater than $2p/n$ and to be especially careful with i th observations greater than $3p/n$. The average value of i th observation is p/n and provided the constant term is in the model, i th observations is always greater than $1/n$. In this work, $p/n = 2/12 = 0.1667$. It is evident from Table 6.3 that no value is greater than twice this value. The graph of leverages against observed data is shown in Figure 4.22

Leverages give an indication of unusual combination of explanatory variables, and residuals indicate observations with an unusual response. It is sometimes useful to have an overall measure of how unusual an observation is, combining both explanatory and response variables. Cook's distances (COO) combines the standardised residuals and the leverages in a formula which ensure that the result can be compared with an F-distribution. Cook and Weisber (1982) suggest that values greater than 50% point of $p(p, n-p)$ distribution usually

provide a good indication of peculiar observation. For this analysis, F distribution with 2 and 12 d.f.

50 % point is 0.73477. The graph of Cook's distances is shown in Figure 4.23 which actually indicated that no observation gives cause for concern.

Figure 4.24 shows the comparison between the simulated and actual measured values of weight of birds in the integrated system using another set of collected data. It is observed that they are in very good accord. Actual weight of bird will be a function of water, feed intake, and other management practises were considered as management factors and were constants in this work.

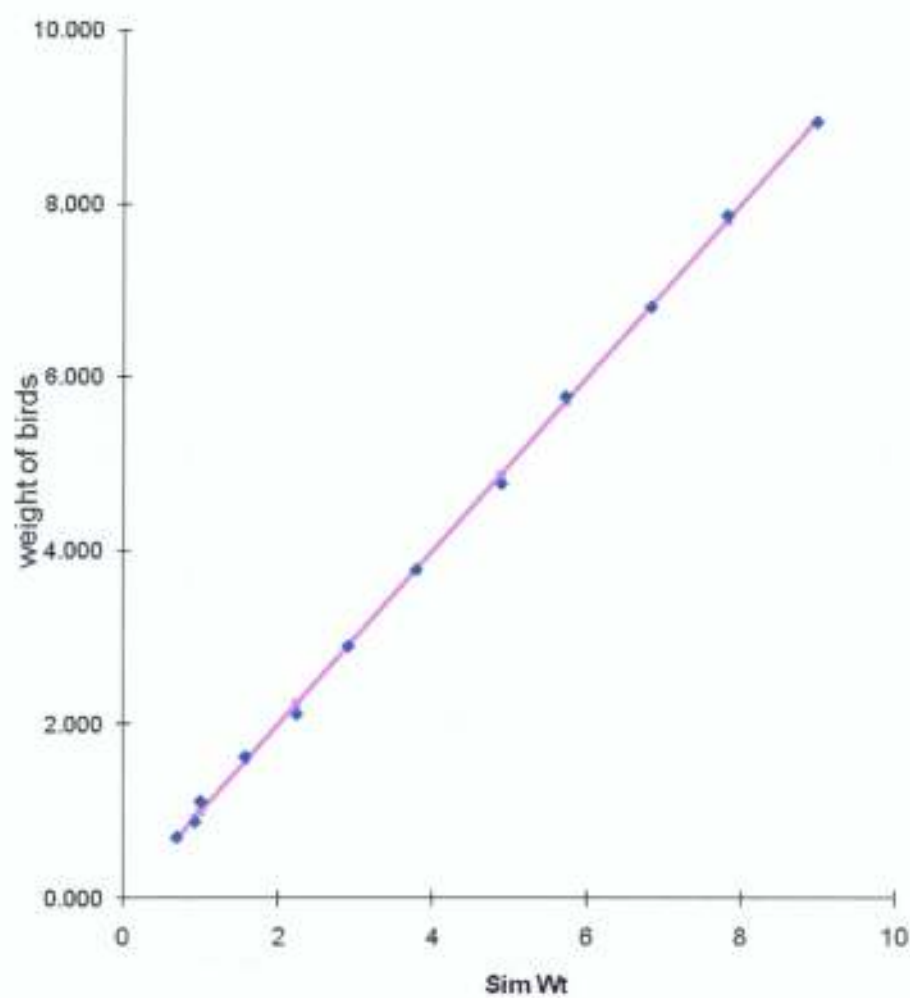


Fig. 4.21 SimWt Line Fit Plot

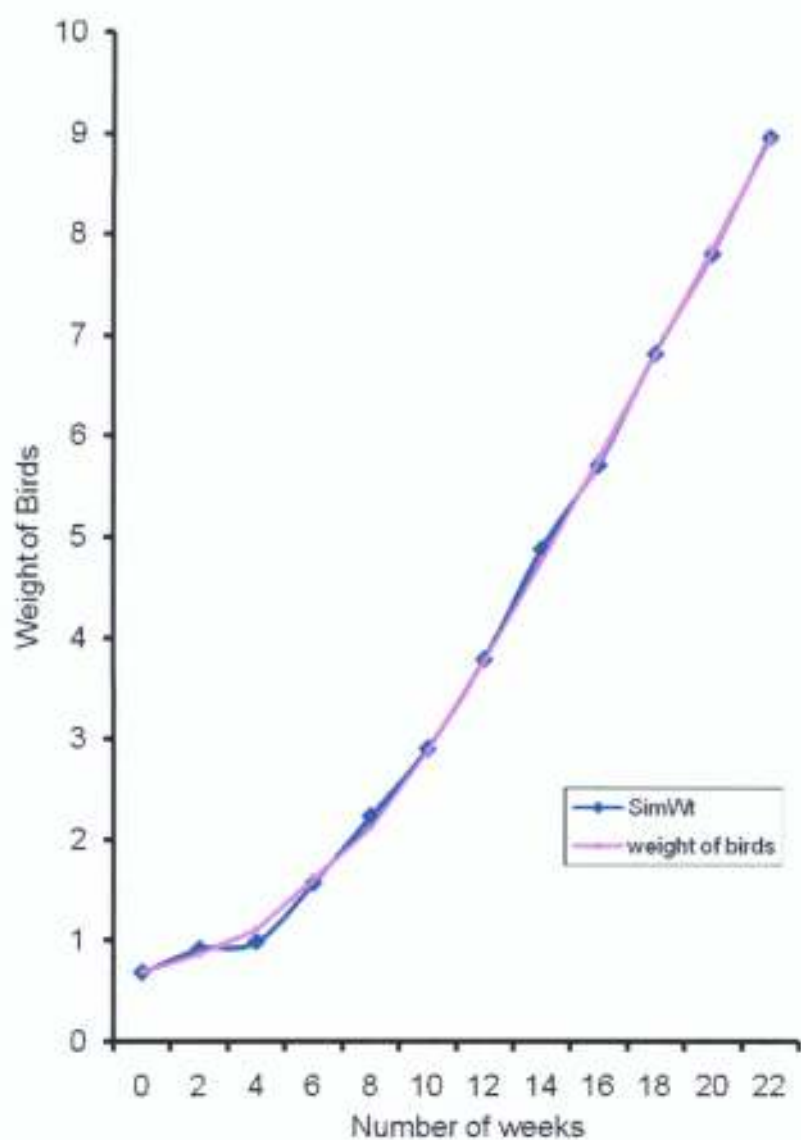


Fig 4.24: Graph of Simulated and measured Weight of Bird against No of Weeks

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

An integration of Poultry and Fish husbandry was developed for the purpose of optimal productivity and the following conclusions can be drawn from the study; it has been possible to integrate poultry and fish husbandry and the waste generated by the poultry serving as a feed for the fish. Droppings from a broiler that was given unlimited access to feed and water was capable of feeding 20 *C. gariepinus* to an average weight of about 0.6 kg without using supplementary feed. The system has shown the possibility of effective poultry waste management technique which ensured that nothing is wasted and waste handling problem is greatly reduced.

Pollution resulting from the use of poultry droppings adversely affected the water quality as well as the growth of the fish. Increase in the volume of droppings led to increase in the Bio-Chemical oxygen demand and Chemical Oxygen demand of the tank water which consequently led to a decrease in the dissolved oxygen. Water turbidity also increased with increased droppings. Other water parameters such as conductivity, chloride and pH values were within acceptable values suggested in literatures.

There was a significant variation in the environmental microclimate inside and outside the housing unit and this led to the development of a simple model which used combined mathematical and statistical models to predict the development of the birds inside the poultry based on environmental influence. The model is simply put as $Wt = 6.2296 - 0.0748HR_{out} + 0.06762HR_{in} + 0.62024T_{in} - 0.84806T_{out} + 0.04704QT + 0.00509Vent$. The developed model was calibrated and validated using multiple regression analysis, the result of which agreed with findings from previous researches.

5.2 Recommendations for Further Studies

From the findings and results of this study, the following recommendations are suggested:

- i. There is need to test other species of fish for the vertical integration system
- ii. Layers should be tested in order to further enhance the benefit of integrated poultry/fish agriculture.
- iii. Environmental parameters were used in the research work to predict the growth of the birds in the study area; there is need to carry out similar studies in other climatic areas of Nigeria.
- iv. Waste water discharged from the pond should be investigated for possible use as manure for growing vegetables.

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APPENDIX A

APPENDIX A1: CALCULATION OF STRESSES IN MEMBERS

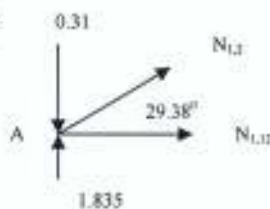
By symmetry, the load at both supports will be equal.

Therefore $R_a + R_b = 0.31 + 0.61 + 0.61 + 0.61 + 0.61 + 0.61 + 0.31 = 5(0.61) + 2(0.31) = 3.67 \text{ kN}$

Since $R_a = R_b$, $R_a + R_b = 2R = 3.67$, $R = 1.835 \text{ kN}$.

Starting from joint 1,

$$\sum_{\uparrow}^+ f_y = 0$$



$$1.835 - 0.31 + N_{12} \sin 29.38 = 0$$

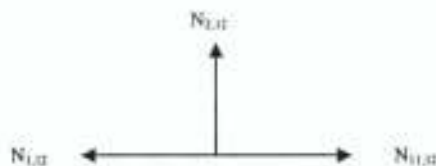
$N_{1,2} = -3.108 \text{ kN}$, the negative sign indicates that the direction is opposite.

$$\sum_{\rightarrow}^+ f_x = 0 \quad N_{1,12} + N_{1,2} \cos 29.38^\circ = 0$$

Therefore, $N_{1,12} = -2.709 \text{ kN}$

Joint 12,

$$\sum_{\uparrow}^+ f_y = 0, \quad N_{2,12} = 0$$



Similarly $\sum_{\rightarrow}^+ f_x = 0$, therefore $N_{11,12} - N_{1,12} = 0$

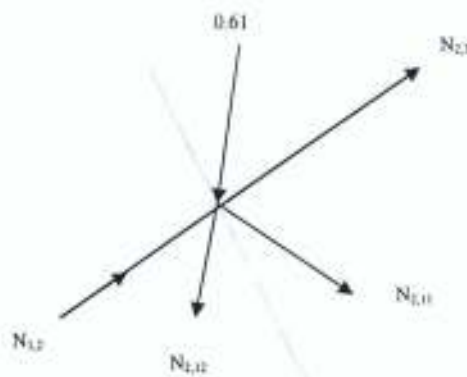
$$N_{11,12} = N_{1,12} = 2.709 \text{ kN}$$

Joint 2,

$$\sum_{\uparrow}^+ f_y = 0,$$

$$N_{2,11} \cos 29.38 + 0.61 \cos 29.38 = 0$$

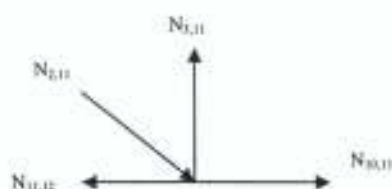
So $N_{2,11} = -0.61 \text{ kN}$



$$\sum \overset{++}{f_x} = 0, -N_{2,11} \cos 60.62^\circ + N_{2,3} - 0.61 \cos 60.62^\circ + N_{1,2} = 0$$

$$\text{Hence } N_{2,3} = 2(0.61 \cos 60.62^\circ) - 3.108 = -2.509 \text{ kN}$$

Joint 11,



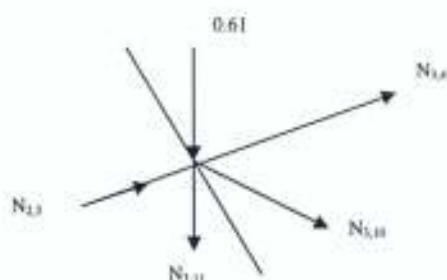
$$\sum \overset{++}{f_y} = 0, -N_{2,11} \cos 60.62^\circ + N_{3,11} = 0$$

$$N_{3,11} = 0.61 \cos 60.62^\circ = 0.304 \text{ kN}$$

$$\sum \overset{++}{f_x} = 0, N_{2,11} \cos 29.38^\circ + N_{10,11} - N_{11,12} = 0$$

$$N_{10,11} = 2.709 - 0.61 \cos 29.38^\circ = 2.177 \text{ kN}$$

Joint 3



$$\sum \overset{++}{f_y} = 0$$

$$N_{3,10} \cos 29.38^\circ + N_{3,11} \cos 29.38^\circ + 0.61 \cos 29.38^\circ = 0$$

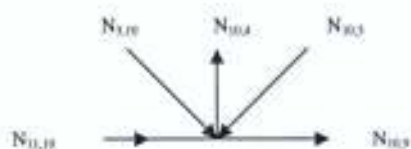
$$N_{3,10} = -0.91 \text{ kN}$$

$$\sum \overset{++}{f_x} = 0, N_{3,10} \cos 60.62^\circ + N_{3,4} - 0.61 \cos 60.62^\circ - N_{3,11} \cos 60.62^\circ + N_{2,3} = 0$$

$$N_{3,4} = 0.91 \cos 60.62^\circ + 0.61 \cos 60.62^\circ + 0.304 \cos 60.62^\circ - 2.509 = -1.61 \text{ kN}$$

Joint 10

$$\sum \overset{++}{f_y} = 0$$



$$N_{10,4} + N_{3,10}\text{Cos}29.38^0 + N_{10,5}\text{Cos}29.38^0 = 0$$

$$N_{10,4} = 1.58 \text{ kN}$$

The same method is applied to calculating stress due to live and wind loads and the results are tabulated as shown in Table 3.1.

TABLE A2: ENVIRONMENTAL PARAMETERS MEASURED IN THE MORNING

Days	Rh _{out}	T _{out}	RH _{in}	T _{in}	RH _{Use2}	T _{und}	RHc ₁	Tc ₁	RHc ₂	Tc ₂	RHc ₃	Tc ₃
1	93.0	24.8	94.3	24.8	94.9	25.0	94.4	25.0	94.6	25.1	94.4	25.2
2	93.1	24.6	95.8	24.8	96.2	24.9	96.0	25.1	95.3	25.1	95.7	25.2
3	90.3	24.9	92.2	24.4	93.6	25.4	94.1	25.6	94.4	25.6	94.7	25.6
4	94.3	24.7	95.0	25.0	95.0	25.1	94.5	25.2	95.1	25.3	94.5	25.3
5	89.2	25.0	92.9	25.6	93.7	25.2	94.8	25.2	95.0	25.0	96.0	25.2
6	94.3	23.0	96.3	23.4	97.5	23.6	91.1	23.6	97.5	23.6	97.9	23.5
7	93.2	24.4	96.1	24.6	96.6	24.8	96.7	24.7	96.7	24.8	96.9	24.8
8	91.1	24.7	94.1	24.9	94.8	25.4	94.4	25.3	95.3	25.0	95.8	25.2
9	92.4	24.5	93.2	24.4	93.7	24.9	93.5	25.0	93.7	25.0	93.8	24.9
10	92.3	24.8	93.4	24.8	94.1	24.8	95.0	24.9	93.4	25.0	93.4	24.8
11	91.4	24.3	93.9	24.6	94.7	24.6	95.4	24.7	95.7	24.8	94.3	24.6
12	96.4	23.7	96.2	23.9	96.4	24.2	96.1	24.2	96.5	24.3	95.0	24.7
13	93.0	23.1	93.3	23.3	93.0	23.5	92.6	23.5	92.8	23.7	92.3	23.8
14	92.2	24.8	93.5	25.2	94.2	25.2	94.6	25.1	95.0	25.1	95.3	25.0
15	95.6	24.1	97.0	24.3	97.5	24.3	97.8	24.5	97.3	24.5	97.6	24.4
16	95.5	23.6	96.5	24.0	96.5	24.2	96.3	24.2	96.7	24.2	96.3	24.4
17	96.8	23.7	97.9	24.1	98.2	24.2	97.9	24.3	97.9	24.3	97.4	24.4
18	96.5	23.6	96.1	24.1	96.8	24.1	96.9	24.2	97.0	24.2	97.8	24.2
19	96.4	23.3	97.1	23.8	97.6	23.9	95.1	24.4	95.8	24.1	96.7	24.5
20	94.2	23.2	92.9	22.9	95.6	23.2	95.1	23.3	95.6	23.2	97.0	23.3
21	91.4	24.6	91.6	24.1	92.1	23.9	93.1	23.9	94.1	23.2	95.7	23.9
22	94.0	22.2	95.6	22.6	95.6	22.7	95.2	22.8	95.6	22.8	96.0	22.8
23	95.6	24.1	98.8	24.6	98.2	24.6	96.2	25.0	94.9	25.2	94.2	25.4
24	95.1	24.1	96.7	24.3	98.0	24.7	98.1	24.7	97.7	24.8	97.1	24.9
25	82.6	22.6	86.2	22.2	88.6	22.4	89.2	22.7	90.9	22.8	89.6	23.2
26	91.4	24.9	93.3	25.1	94.3	25.6	94.3	25.6	95.4	25.6	94.9	25.6
27	91.6	21.7	92.1	21.7	93.0	21.8	93.5	21.6	94.5	21.9	94.0	21.9
28	84.5	22.6	87.5	23.3	89.5	23.2	89.7	23.2	90.0	23.3	90.5	23.5
29	85.7	22.6	89.0	23.3	89.8	23.3	90.7	23.4	90.8	23.7	89.3	23.6
30	91.7	24.3	94.0	24.5	94.9	24.8	94.7	24.7	95.2	24.8	95.1	24.9
31	93.8	20.8	94.1	21.2	95.5	21.3	95.6	21.3	96.0	21.3	95.1	21.3
32	84.3	22.6	86.6	22.9	87.7	22.9	90.1	22.9	92.4	22.8	91.8	22.8
33	90.1	24.2	94.4	24.4	95.2	24.5	95.6	24.4	95.9	24.4	96.0	24.4
34	89.0	24.3	94.1	24.6	94.6	24.7	95.2	24.6	95.9	24.8	95.5	24.8
35	77.7	23.3	83.6	23.7	83.9	23.5	83.8	23.6	84.0	23.6	85.0	23.7
36	89.6	24.7	91.8	25.1	93.2	25.3	93.4	25.4	94.3	25.5	96.1	25.7
37	92.7	25.1	93.6	25.1	94.0	25.3	94.5	25.4	94.1	25.5	96.0	25.6
38	87.4	25.3	94.1	24.9	94.9	25.6	96.2	25.2	96.7	25.2	97.0	25.1
39	92.3	25.7	94.4	25.4	94.8	25.6	95.4	25.9	95.7	25.8	96.1	25.8
40	90.8	24.8	93.4	25.6	94.2	25.7	94.8	25.7	94.7	25.7	94.6	25.4
41	84.8	25.0	88.3	26.5	89.6	26.3	90.5	26.5	91.6	26.4	92.2	26.4
42	91.0	24.8	94.3	24.9	95.6	25.4	95.6	25.4	96.6	25.4	96.9	25.4
43	90.5	25.0	96.6	25.3	95.6	25.0	96.6	25.3	96.7	24.8	97.7	24.9
44	91.8	24.2	93.8	24.7	94.7	24.5	95.9	24.8	96.1	24.8	96.5	24.9
45	86.8	22.7	90.3	23.3	90.9	23.2	91.7	23.4	92.4	23.4	92.6	23.1
46	85.2	27.3	89.8	27.1	90.6	26.7	92.2	26.4	93.5	26.7	92.7	26.7
47	91.6	25.4	94.3	25.4	94.7	25.8	94.9	25.9	94.6	26.0	94.7	25.8
48	92.3	25.2	95.9	25.4	96.3	25.7	96.2	25.7	96.3	25.8	96.9	26.0
49	93.4	24.9	95.1	25.6	95.8	25.6	95.5	25.6	95.6	25.6	95.3	26.3
50	91.0	25.6	91.9	25.8	92.3	26.1	91.7	26.1	91.9	26.2	91.5	26.2

TABLE A3: ENVIRONMENTAL PARAMETERS MEASURED IN THE AFTERNOON

Days	Rh _{out}	T _{out}	RH _{in}	T _{in}	RH _{Und}	T _{und}	RHc ₁	Tc ₁	RHc ₂	Tc ₂	RHc ₃	Tc ₃
1	51.7	33.3	54.6	32.2	53.8	32.4	53.4	33.1	52.4	33.4	53.0	33.9
2	51.9	33.9	52.8	32.8	56.4	33.5	54.5	33.4	54.6	33.6	54.5	33.2
3	57.0	33.3	55.9	31.4	55.5	32.0	57.1	31.7	57.4	32.5	58.5	32.8
4	62.5	31.6	58.5	31.3	60.1	32.1	60.8	31.8	59.4	31.6	59.8	32.8
5	58.8	31.6	59.5	32.9	59.3	32.7	61.1	32.8	62.4	32.1	63.2	32.7
6	59.2	33.2	57.9	31.3	59.8	31.7	61.7	31.0	63.3	31.3	64.9	31.3
7	40.0	34.0	45.0	32.3	49.4	31.9	48.5	31.7	50.2	33.1	46.1	33.7
8	42.7	33.8	43.2	34.6	45.0	32.7	47.1	32.1	47.8	33.9	45.4	34.1
9	46.5	36.3	43.2	33.8	45.3	33.5	48.4	34.3	48.6	34.1	49.5	34.7
10	58.0	31.4	58.1	31.4	59.6	31.2	58.6	31.3	59.8	31.4	60.4	31.6
11	51.3	32.9	53.6	32.6	53.6	32.5	54.7	32.1	55.4	32.6	56.4	32.7
12	63.3	33.0	62.9	32.3	61.7	31.7	63.8	32.6	61.8	32.3	62.6	32.6
13	68.4	30.0	69.1	29.7	69.9	29.9	71.2	30.5	70.4	30.8	69.3	31.1
14	62.3	33.1	60.7	32.5	62.5	31.8	63.3	32.2	64.1	32.1	63.8	32.9
15	59.9	32.7	58.2	32.4	59.6	31.9	61.7	31.6	62.9	31.6	62.6	31.7
16	59.3	32.0	60.1	31.3	61.4	31.6	62.6	31.8	63.5	32.2	63.1	32.3
17	56.9	35.3	60.6	31.2	61.2	32.2	60.3	32.1	61.2	32.3	61.5	32.4
18	59.3	33.5	56.8	33.3	58.1	33.2	58.2	33.2	58.5	33.3	59.4	33.8
19	62.7	26.9	64.4	27.8	82.4	27.5	82.9	27.9	83.9	27.6	84.9	27.7
20	58.1	31.2	57.3	30.4	59.7	29.6	59.6	30.4	62.3	29.7	63.0	29.3
21	61.8	30.8	59.5	30.1	62.1	30.6	62.3	30.7	62.3	30.7	62.5	31.0
22	63.2	32.8	63.1	30.8	63.7	30.9	64.1	31.4	66.5	31.0	63.9	31.5
23	63.9	30.9	64.4	31.8	63.3	31.1	64.4	31.3	65.7	31.7	64.4	31.8
24	58.3	31.8	60.7	32.6	61.9	32.9	62.5	32.7	62.8	32.4	64.5	32.2
25	71.0	30.4	66.6	30.1	69.1	30.4	68.0	29.8	68.2	30.1	66.7	29.9
26	63.0	31.3	64.9	32.1	63.0	32.1	65.8	32.1	64.2	32.2	63.6	32.4
27	58.7	33.3	56.1	32.9	56.6	31.3	59.6	32.1	60.5	31.7	62.8	32.2
28	55.0	33.6	59.4	32.2	59.9	32.8	63.1	32.3	61.5	32.1	61.1	32.3
29	60.7	32.1	61.1	31.1	62.8	31.3	63.7	31.7	63.9	31.2	64.4	31.7
30	69.2	30.5	67.3	29.9	70.3	30.4	68.7	30.1	69.2	30.4	68.9	30.7
31	69.9	26.8	73.4	26.1	81.0	24.4	78.1	25.7	79.1	24.9	80.6	25.3
32	50.9	32.9	53.3	32.2	54.8	31.8	55.3	31.7	55.6	31.9	57.4	31.9
33	63.8	31.6	62.5	30.3	64.5	30.2	63.7	31.0	65.2	30.6	65.4	31.4
34	59.7	33.6	60.5	32.2	63.1	32.7	62.7	32.6	64.7	32.7	64.3	32.4
35	55.5	33.2	58.3	32.3	56.1	31.6	58.3	32.4	62.0	32.4	62.1	31.9
36	51.1	33.4	52.4	32.9	55.7	33.3	55.3	33.4	56.0	33.4	52.4	34.6
37	60.3	33.8	62.7	31.8	61.0	31.3	63.3	31.9	63.9	31.9	64.3	31.9
38	54.2	34.8	57.5	33.5	57.1	32.9	58.5	33.3	59.0	33.0	58.1	32.5
39	61.5	33.4	60.6	31.1	63.2	30.7	64.5	31.5	65.1	31.7	68.0	31.8
40	52.3	34.6	51.0	33.6	52.8	32.8	53.9	33.6	54.7	33.8	54.0	33.7
41	63.9	32.0	64.4	31.3	65.2	31.1	66.7	31.7	66.9	31.6	67.7	31.8
42	63.5	32.7	62.5	32.4	62.7	31.7	64.1	32.0	63.3	32.5	66.3	32.7
43	63.5	31.4	69.4	30.6	71.4	30.9	72.4	30.9	72.3	30.7	71.4	30.4
44	66.8	32.8	67.4	31.3	65.0	32.4	68.1	32.1	70.4	31.5	74.4	31.8
45	60.5	32.6	62.0	30.7	65.6	30.7	65.4	31.1	64.5	31.7	68.9	32.0
46	54.8	35.0	52.6	32.6	56.3	31.8	56.6	32.3	57.7	32.5	57.9	33.8
47	56.0	34.1	56.6	32.3	59.8	32.8	57.2	32.8	58.3	33.1	58.3	33.2
48	62.3	32.0	63.3	31.4	64.4	31.0	65.4	31.3	64.9	31.2	64.7	31.3
49	56.8	34.2	58.4	31.8	59.7	31.9	60.3	31.8	61.5	32.0	61.5	32.2
50	59.7	34.1	57.6	32.6	59.6	32.3	60.6	32.7	60.8	32.6	60.9	32.9

TABLE A4: ENVIRONMENTAL PARAMETERS MEASURED IN THE EVENING

Days	Rh _{out}	T _{out}	RH _{in}	T _{in}	RH _{Und}	T _{und}	RHc ₁	Tc ₁	RHc ₂	Tc ₂	RHc ₃	Tc ₃
1	68.0	29.5	68.6	29.4	69.0	29.3	68.5	29.5	68.4	29.6	68.2	29.5
2	56.9	29.6	57.0	29.3	58.3	29.2	58.5	29.3	59.6	29.3	60.1	29.3
3	59.0	31.3	62.8	31.4	62.5	31.3	62.9	31.4	63.3	31.2	63.8	31.3
4	76.9	27.7	79.5	27.3	80.6	27.4	81.3	27.4	81.6	27.4	82.8	27.6
5	66.2	30.2	65.5	30.3	65.3	30.5	63.5	30.6	64.8	30.7	64.1	30.8
6	60.0	31.2	64.4	31.2	61.2	31.4	61.7	31.6	60.2	31.8	61.9	31.9
7	68.7	29.4	67.6	29.8	65.4	30.5	61.3	30.4	63.0	30.8	62.9	31.2
8	66.4	29.3	68.1	29.2	67.1	29.2	68.6	29.3	69.1	29.2	69.5	29.2
9	61.6	30.1	60.9	30.2	61.1	30.2	61.6	30.2	61.2	30.3	61.1	30.4
10	67.7	29.7	74.3	29.4	76.9	29.1	76.6	29.0	77.4	28.9	78.2	28.8
11	61.9	29.9	63.8	29.7	65.0	29.9	64.3	29.9	63.4	29.8	63.0	29.6
12	65.5	25.4	67.2	25.2	68.2	25.4	67.8	25.4	67.5	25.2	67.6	24.9
13	69.4	30.2	69.7	30.0	69.6	30.1	69.2	30.4	68.9	30.2	69.0	30.3
14	73.1	29.2	73.5	29.2	74.5	29.3	74.4	29.3	74.7	29.3	74.0	29.3
15	61.0	31.2	60.7	31.4	60.3	31.6	59.6	31.7	59.7	31.8	60.4	31.9
16	75.6	26.2	69.9	27.0	71.0	26.6	72.0	27.1	72.2	26.5	73.3	26.5
17	65.6	30.8	62.3	31.0	64.0	31.0	61.9	31.3	62.3	31.4	61.8	31.2
18	70.7	29.1	72.1	29.2	72.9	29.3	72.9	29.3	72.9	29.3	72.3	29.2
19	87.6	25.2	89.3	25.2	90.2	25.3	90.4	25.3	91.5	25.5	91.6	25.5
20	77.2	27.1	78.6	27.1	79.8	27.1	81.0	27.2	81.0	27.2	81.6	27.2
21	70.8	28.9	75.9	28.0	79.2	28.0	80.8	28.1	81.5	28.0	83.6	28.1
22	73.2	29.4	76.6	28.4	75.0	28.4	74.3	28.4	74.5	28.3	76.1	28.2
23	74.5	28.4	77.2	29.0	78.3	29.0	78.1	28.9	78.3	29.0	77.8	28.9
24	68.4	30.6	67.4	30.8	68.0	30.8	68.2	30.9	68.5	30.8	68.2	30.8
25	70.3	29.2	73.2	29.2	74.6	29.2	74.1	29.1	74.4	29.2	75.5	29.2
26	67.9	30.9	66.1	31.2	67.0	31.2	66.9	31.3	66.9	31.3	66.0	31.2
27	66.8	29.7	63.5	29.9	64.3	29.8	64.8	29.9	64.3	30.1	64.6	30.1
28	69.8	29.5	68.8	29.7	68.6	29.8	69.1	30.1	68.9	30.1	66.8	30.2
29	72.8	29.2	72.1	29.7	72.7	29.7	71.9	29.7	72.1	29.7	71.2	29.7
30	60.7	28.8	63.9	28.9	65.3	29.0	65.7	29.2	65.9	28.9	66.1	28.7
31	72.1	27.7	76.9	27.2	78.1	26.9	80.6	26.9	82.1	26.8	84.9	26.7
32	56.6	31.8	59.5	31.8	56.7	31.8	56.2	32.1	55.8	31.9	57.0	31.9
33	59.0	31.7	58.5	32.7	60.5	32.1	58.9	32.3	59.6	32.4	56.8	32.2
34	61.9	31.9	64.2	30.9	59.7	30.6	53.4	29.7	51.0	30.1	49.5	30.2
35	64.9	29.8	65.1	30.4	65.2	30.1	66.2	30.3	66.4	30.2	66.0	30.2
36	73.3	28.3	76.1	28.9	80.1	29.0	79.5	29.1	81.1	29.0	80.5	29.1
37	79.5	27.5	77.5	28.1	80.7	28.2	79.5	28.3	80.8	28.4	79.2	28.7
38	62.2	33.0	59.4	32.1	61.2	31.9	61.3	32.6	62.6	32.3	63.3	32.4
39	70.6	30.2	76.1	29.8	78.1	29.7	76.2	29.7	76.5	29.8	77.9	29.7
40	71.7	31.5	73.0	30.1	79.6	29.7	78.5	29.9	73.6	29.8	72.2	30.1
41	73.0	29.1	76.2	29.7	77.3	29.5	77.9	29.5	78.3	29.4	79.8	29.2
42	69.3	30.5	70.3	30.7	71.6	30.4	71.2	30.6	71.1	30.7	71.4	30.6
43	67.2	30.7	68.5	31.0	70.3	30.5	70.6	30.9	69.7	30.8	71.0	30.9
44	66.1	28.3	70.4	26.4	75.7	26.3	74.7	26.2	76.3	26.2	74.3	26.1
45	65.2	31.6	62.1	31.6	63.3	31.5	64.1	31.7	63.6	31.8	61.9	31.8
46	60.5	32.5	59.5	32.7	60.8	32.7	59.2	32.9	58.1	33.0	57.6	33.1
47	60.1	32.4	60.6	31.8	66.6	31.9	65.3	32.0	68.0	31.8	60.1	32.0
48	58.8	31.7	59.6	31.9	60.8	31.8	63.2	32.1	61.3	32.1	60.4	31.7
49	63.5	31.9	74.0	31.1	71.9	30.4	72.7	30.5	75.6	30.2	78.0	29.9
50	74.0	29.7	76.3	29.4	77.8	29.3	78.1	29.4	79.3	29.4	79.1	29.5

TABLE A5: WATER PARAMETERS IN POND 1

Days	Ph	conductivity	turbidity	Colour	Do2	Bod	cod	nitrate	Cl	nh3	salinity
1	6.80	0.45	20.00	18.00	8.20	17.20	56.00	0.00	17.60	0.60	0.01
2	6.15	0.51	23.00	20.00	8.02	18.40	65.00	0.00	18.40	0.00	0.02
3	6.90	0.46	25.00	22.00	8.09	19.60	77.00	0.00	22.10	0.00	0.01
4	6.49	0.51	28.00	24.00	8.10	20.80	89.00	0.02	22.30	0.00	0.02
5	6.88	0.55	34.00	27.00	8.14	23.70	92.00	0.01	23.70	0.00	0.02
6	7.03	0.41	38.00	30.00	8.12	38.50	99.00	0.02	23.00	0.01	27.50
7	7.02	0.61	42.00	34.00	7.90	40.80	106.00	0.00	24.00	0.03	27.10
8	6.70	0.39	46.00	38.00	7.40	46.40	119.00	0.01	24.00	0.00	0.01
9	6.57	0.38	50.00	40.00	7.20	48.70	126.00	0.01	24.20	0.00	0.02
10	6.58	0.45	58.00	45.00	7.00	49.90	134.00	0.02	24.70	0.00	0.02
11	6.86	0.45	62.00	47.00	6.70	54.80	154.00	0.00	25.00	0.60	0.01
12	6.15	0.52	63.00	50.00	6.60	59.40	162.00	0.01	25.60	0.00	0.02
13	6.58	0.47	66.00	53.00	6.40	60.50	176.00	0.00	26.50	0.00	0.01
14	6.49	0.53	78.00	58.00	6.40	64.70	187.00	0.02	26.50	0.00	0.02
15	6.88	0.56	85.00	62.00	6.30	72.30	192.00	0.01	26.20	0.00	0.02
16	7.03	0.46	86.00	65.00	6.30	83.20	195.00	0.00	25.60	0.01	27.50
17	7.02	0.65	88.00	69.00	6.20	95.50	197.00	0.00	26.20	0.03	27.10
18	6.70	0.36	89.00	71.00	5.60	98.80	202.00	0.01	25.00	0.00	0.01
19	6.57	0.40	90.00	74.00	5.60	104.30	213.00	0.01	24.70	0.00	0.02
20	6.58	0.48	103.00	78.00	5.40	120.20	223.00	0.02	25.00	0.00	0.02
21	6.00	0.46	108.00	81.00	5.10	134.30	228.00	0.00	24.50	0.60	0.01
22	6.15	0.57	112.00	84.00	5.10	142.80	235.00	0.00	26.50	0.00	0.02
23	6.58	0.44	125.00	89.00	4.70	148.20	245.00	0.00	27.30	0.00	0.01
24	6.49	0.58	132.00	93.00	4.60	156.70	248.00	0.20	29.40	0.00	0.02

TABLE A6: WATER PARAMETERS IN POND 2

	Ph	conductivity	turbidity	colour	Do2	Bod	cod	nitrate	cl	nh3	salinity
1	6.80	0.45	20.00	18.00	8.20	17.16	56.00	0.00	17.60	0.60	0.02
2	6.60	0.61	27.00	23.00	7.80	21.45	95.00	0.00	20.50	0.00	0.02
3	6.50	0.65	32.00	26.00	7.60	38.61	122.00	0.00	22.20	0.00	0.03
4	6.66	0.58	35.00	28.00	7.60	38.61	133.00	0.02	26.60	0.20	0.02
5	6.30	0.51	39.00	33.00	7.50	51.48	154.00	0.02	26.60	0.30	0.02
6	6.85	0.50	45.00	37.00	7.40	60.06	165.00	0.00	28.00	0.00	0.02
7	6.85	0.78	49.00	42.00	7.30	60.06	170.00	0.00	28.00	0.00	0.04
8	7.00	0.53	52.00	45.00	7.11	79.00	180.00	0.01	27.70	0.00	0.02
9	6.70	0.53	57.00	48.00	6.65	90.09	185.00	0.02	28.80	0.00	0.02
10	6.70	0.53	65.00	50.00	6.25	90.09	190.00	0.02	28.00	0.00	0.02
11	7.00	0.48	76.00	52.00	6.13	94.38	190.00	0.00	30.20	0.60	0.02
12	6.80	0.62	83.00	55.00	6.08	100.00	200.00	0.00	30.20	0.00	0.02
13	7.20	0.68	98.00	58.00	5.90	102.96	210.00	0.00	31.40	0.00	0.03
14	7.70	0.58	107.00	61.00	5.60	107.25	220.00	0.02	31.30	0.00	0.02
15	6.50	0.53	107.00	64.00	5.45	120.12	223.00	0.02	30.60	0.00	0.02
16	6.85	0.51	117.00	67.00	5.00	128.70	225.00	0.00	31.70	0.00	0.02
17	6.85	0.68	119.00	70.00	4.80	137.28	240.00	0.00	31.70	0.00	0.04
18	6.54	0.54	123.00	73.00	4.60	141.00	243.00	0.01	30.20	0.00	0.02
19	6.70	0.57	130.00	77.00	4.40	148.00	240.00	0.02	29.60	0.00	0.02
20	6.70	0.58	137.00	81.00	4.30	159.00	255.00	0.02	29.50	0.00	0.02
21	7.00	0.49	148.00	83.00	4.10	167.31	255.00	0.00	29.40	0.30	0.02
22	7.70	0.64	150.00	86.00	4.00	173.00	263.00	0.00	29.60	0.20	0.02
23	6.80	0.68	156.00	92.00	3.80	177.00	272.00	0.00	31.20	0.00	0.03
24	6.66	0.59	160.00	97.00	3.70	186.00	283.00	0.02	32.80	0.00	0.02

TABLE A7: WATER PARAMETERS IN POND 3

	Ph	conductivity	turbidity	colour	do2	Bod	cod	Nitrate	cl	nh3	salinity
1	6.80	0.45	20.00	18.00	8.20	17.20	56.00	0.00	17.60	0.70	0.02
2	6.90	0.72	33.00	24.00	7.50	39.50	130.00	0.00	18.90	0.65	0.03
3	7.00	0.73	35.00	28.00	7.20	47.50	158.00	0.00	21.20	0.00	0.03
4	7.30	0.65	43.00	31.00	7.00	54.70	168.00	0.02	24.70	0.00	0.02
5	6.70	0.71	54.00	36.50	6.90	65.70	185.00	0.02	28.40	0.00	0.02
6	7.08	0.31	60.00	40.00	6.30	73.10	195.00	0.00	30.20	0.00	0.01
7	6.91	0.71	66.00	45.20	6.30	82.30	208.00	0.00	32.00	0.54	0.03
8	6.60	0.59	75.00	49.60	5.90	96.70	221.70	0.02	32.80	0.00	0.02
9	6.58	0.63	79.00	52.00	5.40	103.40	235.00	0.02	32.70	0.00	0.02
10	6.85	0.63	87.00	55.00	5.10	112.20	238.00	0.02	33.10	0.00	0.02
11	7.00	0.48	94.00	58.00	5.10	121.40	249.00	0.00	34.00	0.70	0.02
12	6.80	0.73	108.00	59.00	4.80	134.80	248.00	0.01	33.10	0.00	0.03
13	7.40	0.77	116.00	62.00	4.40	139.10	254.30	0.00	34.90	0.00	0.03
14	7.80	0.75	127.00	64.00	3.90	142.20	254.00	0.02	35.60	0.00	0.02
15	7.80	0.72	135.00	68.00	3.70	147.50	265.00	0.02	35.30	0.00	0.02
16	7.08	0.42	147.00	69.00	3.50	150.10	270.00	0.00	35.70	0.00	0.01
17	6.91	0.72	158.00	72.00	3.40	154.30	273.00	0.00	35.40	0.00	0.03
18	6.53	0.57	168.00	75.00	3.30	155.00	275.00	0.02	36.00	0.00	0.02
19	6.58	0.69	174.00	79.00	3.10	167.90	283.00	0.02	36.00	0.00	0.02
20	6.85	0.67	186.00	83.00	2.20	173.50	288.00	0.02	36.00	0.00	0.02
21	7.10	0.59	196.00	85.00	2.00	185.40	288.00	0.00	36.30	0.70	0.02
22	6.90	0.75	203.00	89.00	1.80	193.20	295.00	0.00	36.00	0.00	0.03
23	6.90	0.79	213.00	94.00	1.70	201.10	293.00	0.00	35.70	0.60	0.03
24	7.20	0.80	234.00	99.00	1.60	223.00	298.00	0.02	36.80	0.56	0.02

TABLE A8: WATER PARAMETERS IN CONTROL POND

	Ph	conductivity	turbidity	colour	Do2	Bod	Cod	nitrate	Cl	nh3	salinity
1	7.10	0.45	18.00	18.00	8.20	17.20	45.00	0.00	17.60	0.60	0.01
2	6.10	0.48	20.00	21.00	8.02	18.40	55.00	0.00	17.80	0.00	0.02
3	7.00	0.45	22.00	22.00	8.09	19.60	56.00	0.00	22.10	0.00	0.01
4	6.60	0.47	24.00	23.00	8.10	20.80	62.00	0.02	24.40	0.00	0.02
5	7.00	0.52	28.00	25.00	8.14	23.70	66.00	0.01	24.40	0.00	0.02
6	7.03	0.41	30.00	26.10	8.12	38.50	68.00	0.02	24.70	0.01	27.50
7	7.02	0.58	32.00	30.40	7.90	40.80	72.00	0.00	25.70	0.03	27.10
8	6.70	0.34	36.00	33.90	7.40	46.40	74.00	0.01	25.70	0.00	0.01
9	6.57	0.31	38.00	36.00	7.20	48.70	76.00	0.01	26.70	0.00	0.02
10	6.58	0.43	43.00	40.90	7.00	49.90	77.00	0.02	26.20	0.00	0.02
11	6.20	0.41	49.00	44.00	6.70	54.80	79.00	0.00	27.70	0.60	0.01
12	6.15	0.48	55.00	47.00	6.60	59.40	82.00	0.01	27.70	0.00	0.02
13	6.60	0.44	59.00	50.40	6.40	60.50	83.00	0.00	28.20	0.00	0.01
14	6.80	0.50	62.00	53.90	6.40	64.70	85.00	0.02	27.70	0.00	0.02
15	7.00	0.52	68.00	58.30	6.30	72.30	87.00	0.01	27.40	0.00	0.02
16	7.20	0.43	75.00	65.00	6.40	73.10	89.00	0.00	27.40	0.01	27.50
17	7.02	0.60	79.00	69.00	6.50	75.20	91.00	0.00	28.00	0.03	27.10
18	6.70	0.31	82.00	71.00	6.30	75.30	93.00	0.01	27.20	0.00	0.01
19	6.57	0.36	86.00	74.00	6.30	74.20	95.00	0.01	27.40	0.00	0.02
20	6.80	0.42	94.00	78.00	6.40	72.50	102.00	0.02	27.70	0.00	0.02
21	6.50	0.42	98.00	81.00	6.50	75.60	105.00	0.00	27.00	0.60	0.01
22	6.20	0.53	106.00	84.00	6.60	76.20	109.00	0.00	28.40	0.00	0.02
23	6.80	0.39	112.00	90.00	6.70	78.20	112.00	0.00	28.70	0.00	0.01
24	6.70	0.54	122.00	91.00	6.80	79.20	118.00	0.20	32.20	0.00	0.02

TABLE A9: ANOVA OF AVERAGE WEIGHT OF FISH IN PONDS AT 6TH WEEK

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
WtavP1	4	157	39.25	295.5833
WtavP2	4	136	34	168
WtavP3	4	129	32.25	168.25
WtavP4	4	177	44.25	465.5833

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	353.6875	3	117.8958	0.429721	0.73546	3.4903
Within Groups	3292.25	12	274.3542			
Total	3645.938	15				

TABLE A10: ANOVA OF AVERAGE WEIGHT OF FISH IN PONDS AT 24TH WEEK

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
WtavP1	24	6797	283.2083	34079.13
WtavP2	24	4806	200.25	15249.15
WtavP3	24	3768	157	8050.696
WtavP4	24	9478	394.9167	110314.7

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	789956.4	3	263318.8	6.280948	0.000633	2.703594
Within Groups	3856954	92	41923.42			
Total	4646911	95				

Table A11: Multiple Stepwise Regression analysis of outside Relative humidity on development of Poultry Birds

ANOVA for regression of Wbird
on Rout

Source	df	SS	MS	F value	Prob>F
Regression	1	0.398038	0.39804	0.04	0.8381
Residual	10	90.5029	9.0503		
Total	11	90.9009			

R-squared = 0.0044

:
Multiple Regression

EST

REGRESSION COEFFICIENTS

Y-variate: Wbird

Param.	Estimate	SE	t	Prob> t
Const	2.1218	8.749	0.24	0.8133
Rout	0.03618	0.1725	0.21	0.8381

:

Table A12: Multiple Stepwise Regression analysis of inside Relative humidity on development of Poultry Birds

ADD 'Rin'

Change	df	SS	MS	F value	Prob>F
Original	1	0.398038	0.39804	0.04	0.8466
Added	1	0.092587	0.09259	0.01	0.9256
Residual	9	90.4103	10.046		
Total	11	90.9009			

:
Multiple Regression

EST

REGRESSION COEFFICIENTS

Y-variate: Wbird

Param.	Estimate	SE	t	Prob> t
Const	5.2609	33.97	0.15	0.8803
Rout	0.06591	0.359	0.18	0.8584
Rin	-0.07507	0.782	-0.10	0.9256

:

Table A13: Multiple Stepwise Regression analysis of inside Temperature on development of Poultry Birds

ADD 'Tin'

Change	df	SS	MS	F value	Prob>F
Original	2	0.490625	0.24531	0.04	0.9623
Added	1	39.5521	39.552	6.22	0.0373
Residual	8	50.8582	6.3573		
Total	11	90.9009			

:
Multiple Regression

EST

REGRESSION COEFFICIENTS

Y-variate: Wbird

Param.	Estimate	SE	t	Prob> t
Const	39.407	30.29	1.30	0.2295
Rout	0.06816	0.2856	0.24	0.8174
Rin	-0.1019	0.6222	-0.16	0.8740
Tin	-1.0418	0.4177	-2.49	0.0373

:

Table A14: Multiple Stepwise Regression analysis of outside Temperature on development of Poultry Birds

ADD 'Tout'

Change	df	SS	MS	F value	Prob>F
Original	3	40.0428	13.348	6.29	0.0213
Added	1	35.9951	35.995	16.95	0.0045
Residual	7	14.863	2.1233		
Total	11	90.9009			

:
Multiple Regression

EST

REGRESSION COEFFICIENTS

Y-variate: Wbird

Param.	Estimate	SE	t	Prob> t
Const	-64.991	30.81	-2.11	0.0729
Rout	0.76712	0.2368	3.24	0.0143
Rin	-1.1544	0.4412	-2.62	0.0346
Tin	-9.0863	1.969	-4.62	0.0024
Tout	12.018	2.919	4.12	0.0045

:

Table A15: Multiple Stepwise Regression analysis of Total Heat on development of Poultry Birds

ADD 'Qt'

Change	df	SS	MS	F value	Prob>F
Original	4	76.0379	19.009	1807.90	0.0000
Added	1	14.7999	14.8	1407.55	0.0000
Residual	6	0.063088	0.01051		
Total	11	90.9009			

:
Multiple Regression

EST

REGRESSION COEFFICIENTS

Y-variate: Wbird

Param.	Estimate	SE	t	Prob> t
Const	6.3076	2.883	2.19	0.0713
Rout	-0.059	0.0276	-2.14	0.0765
Rin	0.04918	0.0446	1.10	0.3128
Tin	0.64681	0.2941	2.20	0.0702
Tout	-0.8646	0.4001	-2.16	0.0740
Qt	0.04819	0.0013	37.52	0.0000

:

Table A16: Multiple Stepwise Regression analysis of Ventilation on development of Poultry Birds

ADD 'Vent'

Change	df	SS	MS	F value	Prob>F
Original	5	90.8378	18.168	1559.20	0.0000
Added	1	0.004829	0.00483	0.41	0.5481
Residual	5	0.058259	0.01165		
Total	11	90.9009			

:
Multiple Regression

EST

REGRESSION COEFFICIENTS

Y-variate: Wbird

Param.	Estimate	SE	t	Prob> t
Const	6.2296	3.038	2.05	0.0955
Rout	-0.0748	0.038	-1.97	0.1064
Rin	0.06762	0.055	1.23	0.2739
Tin	0.62024	0.3123	1.99	0.1038
Tout	-0.84806	0.422	-2.01	0.1007
Qt	0.04704	0.0022	21.03	0.0000
Vent	0.00509	0.0079	0.64	0.5481

FIT 'Rout' 'Rin' 'Tin' 'Tout' 'Qt' 'Vent' ;SRE X22

ANOVA for regression of Wbird
on Rout Rin Tin Tout Qt Vent

Source	df	SS	MS	F value	Prob>F
Regression	6	90.8427	15.14	1299.40	0.0000
Residual	5	0.058259	0.01165		
Total	11	90.9009			

R-squared = 0.9994

APPENDIX B

Table B1: Weight of Fish in tank 1 (Replicate 1)

Wks	Weight of Fish (g)																			
0	20	16	18	17	19	20	20	22	23	24	18	17	17	19	17	20	23	22	21	18
2	45	41	43	47	49	42	43	44	40	40	41	42	43	41	45	48	47	49	50	41
4	78	74	75	78	78	79	80	81	81	79	79	78	75	74	73	73	74	75	76	78
6	125	121	121	122	125	128	129	130	120	121	125	128	128	125	121	120	121	125	126	128
8	177	174	176	177	177	179	176	174	177	179	176	177	180	180	181	179	177	176		
10	232	230	232	233	234	236	230	229	228	230	231	234	232	231	234	232	230	235		
12	289	289	285	291	290	292	289	288	287	286	285	288	289	291	288	292	293	286		
14	350	348	346	349	350	351	354	348	349	349	350	351	352	349	348	350	350	351		
16	408	404	412	410	409	405	408	408	407	410	412	409	407	406	408	407	404	406		
18	461	460	461	464	463	459	458	458	459	460	461	462	461	461	458	459	460	459		
20	511	509	508	512	514	512	511	514	512	511	512	509	508	509	510	511	510	512		
22	558	554	555	562	561	561	558	557	558	558	560	557	554	552	551	563	561	562		
24	581	579	578	580	581	584	580	581	582	583	584	580	581	580	578	579	578	579		

Table B2: Weight of Fish in tank 2 (Replicate 1)

Experiment A tank 2

Experiment A tank 2																				
Wks	Weight of Fish (g)																			
0	19	20	16	17	20	20	21	24	23	22	21	20	20	21	18	19	20	21	23	17
2	38	34	34	37	38	42	41	40	39	38	38	37	34	35	35	37	34	35	37	38
4	63	60	60	61	67	65	63	62	60	65	67	65	65	61	64	66	63	63	67	67
6	92	90	90	96	96	95	96	90	88	87	90	89	87	88	88	88	89	89	90	90
8	129	125	124	130	130	129	132	126	126	126	128	129	128	127	125	127	129			
10	169	170	173	173	165	164	171	171	169	169	170	171	172	169	167	168	169			
12	209	205	204	203	213	209	209	210	212	212	213	209	208	207	206	209	208			
14	249	250	251	245	246	246	247	247	248	249	250	251	252	245	244	246	247			
16	288	284	285	285	286	292	291	294	286	285	284	291	292	288	289	287	289			
18	323	320	321	323	326	326	323	324	324	325	324	323	321	320	327	328	323			
20	354	350	353	354	358	350	351	355	349	348	351	352	354	354	353	349	348			
22	376	372	372	377	377	376	376	376	379	376	372	379	378	377	376	378	379			
24	384	380	381	384	388	387	387	389	388	384	383	383	382	385	389	388	380			

Table B3: Weight of Fish in tank 3 (Replicate 1)

Wks	Weight of Fish (g)																			
0	19	17	22	20	15	23	21	16	19	25	18	24	23	18	15	22	20	16	15	20
2	33	35	29	28	34	37	29	30	32	34	33	30	29	36	33	31	33	36	37	28
4	60	56	59	62	55	64	60	57	59	61	63	65	57	59	56	60	63	65	55	59
6	80	76	79	82	75	84	80	75	77	81	83	84	77	79	80	83	85			
8	106	102	104	110	109	107	103	105	104	108	107	103	111	105	102	106	104			
10	135	132	140	133	136	134	139	140	138	135	141	131	134	137	139	131	133			
12	166	162	170	169	165	171	163	165	169	168	170	163	168	167	162	169	171			
14	196	197	192	201	198	193	195	197	199	200	196	193	194	196	199	201	199			
16	225	221	223	230	229	227	226	222	224	227	228	220	229	225	221	223	227			
18	250	251	253	245	246	249	254	252	250	247	249	250	246	253	255	246	249			
20	268	264	264	272	270	265	268	272	273	265	269	270	272	271	264	266	268			
22	277	273	280	279	282	274	275	279	280	273	276	278	281	282	277	274	282			
24	280	280	276	278	281	282	283	277	279	276	281	283	284	277	279	275	280			

Table B4: Weight of Fish in tank 4 (Replicate 1)

Wks	Weight of Fish (g)																			
0	24	20	23	16	17	19	16	18	19	24	22	21	20	17	16	23	22	24	22	18
2	52	48	56	54	55	49	51	56	53	51	50	52	49	48	52	53	49	56	48	51
4	60	85	87	68	94	92	60	91	93	85	86	89	60	94	86	87	88	90	89	83
6	136	131	132	134	138	138	140	139	136	135	133	132	139	132	134	136	137	139	136	132
8	188	183	190	191	193	184	189	186	188	187	190	192	184	187	186	188	193	192	191	189
10	248	246	250	247	245	249	250	253	245	247	251	253	245	247	251	252	250	249	240	252
12	316	312	319	320	311	315	317	316	314	320	321	319	315	316	317	320	321	314	312	
14	390	395	399	400	391	397	394	393	398	396	392	391	394	400	392	397	396	395	391	
16	493	498	500	501	503	502	494	497	496	499	496	502	501	494	495	496	499	503	501	
18	645	640	649	647	645	643	641	640	642	648	648	650	643	645	647	649	641	643	645	
20	836	831	833	833	835	837	839	840	841	840	839	836	834	832	835	837	839	832	832	
22	1026	1021	1023	1025	1027	1029	1031	1030	1028	1026	1024	1022	1023	1025	1027	1029	1031	1027	1028	
24	1116	1118	1122	1124	1126	1121	1123	1123	1125	1119	1121	1125	1118	1120	1122	1124	1117	1121	1120	

Table B5: Weight of Fish in tank 1 (Replicate 2)

Wks	Weight of Fish (g)																			
0	20	15	25	16	17	17	18	19	23	24	20	16	19	21	22	23	16	18	21	15
2	46	41	51	45	47	48	49	51	50	42	44	43	45	46	48	49	50	41	43	41
4	80	75	85	77	76	79	78	84	85	84	84	83	82	80	76	78	78	75	79	85
6	125	120	130	122	121	122	123	120	129	128	127	129	130	127	127	128	121	122	129	130
8	180	175	185	183	176	177	179	178	178	179	183	182	181	185	184	184	185	183	183	188
10	231	237	228	229	229	230	230	234	235	226	226	230	238	229	229	230	230	231		
12	271	270	271	276	277	268	265	265	276	277	269	269	270	271	271	271	271	268		
14	354	359	380	350	353	350	351	358	351	352	361	362	354	355	358	359	350	382		
16	410	408	409	409	407	415	413	412	412	407	408	413	414	414	413	407	406	410		
18	483	485	480	458	457	456	457	469	470	467	466	462	463	463	460	462	466	464		
20	515	517	520	521	510	509	514	513	512	512	513	521	520	520	519	518	519	515		
22	560	563	566	555	558	557	554	559	560	563	568	567	568	554	553	555	554	566		
24	566	569	570	560	559	559	560	562	564	565	568	568	567	567	569	563	563	564		

Table B6: Weight of Fish in tank 2 (Replicate 2)

Wks	Weight of Fish (g)																			
0	20	15	25	16	18	18	17	19	24	24	20	22	23	23	22	25	17	18	21	22
2	38	42	43	42	32	31	33	35	37	37	39	39	40	41	41	31	34	34	35	36
4	65	60	59	70	71	61	60	59	65	65	63	62	64	65	66	67	67	68	61	61
6	90	84	87	86	87	89	89	95	92	90	91	93	90	98	93	92	82	85	88	89
8	127	121	133	134	122	125	126	123	121	128	129	130	135	121	123	124	126	127		
10	170	178	164	165	167	168	177	175	175	169	169	171	172	175	164	163	163	162		
12	207	202	203	202	210	211	212	202	203	210	207	208	207	207	207	204	205	205		
14	247	249	250	241	243	245	247	243	248	251	253	253	247	247	249	248	251	253		
16	290	285	284	290	296	286	284	282	283	284	290	290	288	289	288	287	286	286		
18	321	319	318	320	325	318	316	317	315	320	326	327	316	319	318	317	317	316		
20	352	358	356	353	354	352	350	352	346	345	344	356	352	354	355	357	358	344		
22	374	379	380	380	374	370	368	367	369	369	370	371	372	377	378	379	377	380		
24	382	390	378	379	377	376	390	389	388	377	387	386	377	378	387	386	390	391		

Table B7: Weight of Fish in tank 3 (Replicate 2)

Wks	Weight of Fish (g)																			
0	17	19	25	24	25	25	24	23	26	15	14	16	17	18	21	20	21	23	20	15
2	38	32	33	34	32	31	38	38	40	38	43	44	42	38	37	38	36	38	38	39
4	82	60	64	68	69	70	61	63	63	63	63	62	64	69	68	56	56	54	53	
6	82	80	81	82	83	84	88	78	77	76	79	79	86	86	81	81	80			
8	112	107	108	111	108	100	106	108	112	113	114	112	112	100	115	114	115			
10	140	132	128	140	145	146	143	141	141	143	141	142	147	135	129	130	134			
12	168	159	160	158	159	160	161	162	163	163	163	162	167	167	168	168	165			
14	198	190	198	202	201	202	203	191	192	195	195	196	197	199	199	200	198			
16	224	219	218	218	221	222	222	228	227	230	231	223	224	218	219	230	223			
18	252	250	251	258	248	249	249	250	252	252	253	252	263	255	256	258	248			
20	265	260	261	270	271	272	272	261	261	261	266	265	265	264	265	260	270			
22	277	278	276	277	279	269	274	277	276	276	282	281	279	280	278	277	277			
24	282	281	286	278	278	276	279	282	281	281	286	283	285	284	279	282	282			

Table B8: Weight of Fish in tank 4 (Replicate 2)

B: Tank 4

Wks	Weight of Fish (g)																			
0	19	23	15	16	19	24	25	23	21	21	24	23	25	23	21	19	20	21	26	23
2	48	40	55	52	43	44	45	45	46	47	48	49	44	45	49	50	51	51	52	55
4	87	82	87	87	89	89	90	82	83	85	89	90	92	82	82	84	88	88	89	87
6	140	135	138	137	135	139	141	145	146	135	138	139	140	135	136	136	137	140	141	147
8	190	185	184	198	199	199	189	190	191	192	193	192	190	198	197	195	194	193		
10	250	254	249	250	250	253	258	259	247	257	248	254	250	246	246	250	251	254		
12	320	320	319	316	315	324	325	316	321	325	326	324	320	319	318	316	317	320		
14	397	388	388	390	389	389	387	388	390	392	400	412	408	405	404	402	404	404		
16	500	490	497	492	494	495	494	503	512	528	524	500	501	498	497	499	491	494		
18	647	643	640	652	654	657	659	647	649	640	639	638	647	649	645	643	641	640		
20	850	840	845	850	858	857	856	845	850	851	852	853	852	850	851	850	840	845		
22	950	945	947	945	948	950	958	960	945	945	950	945	946	950	951	951	950	946		
24	1010	1015	1018	1007	1006	1002	1001	1002	1003	1002	1008	1009	1012	1013	1006	1009	1010	1009		