KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

MODELLING THE FEED MIX FOR POULTRY PRODUCTION

(THE CASE OF ADAMA MUSA FARMS, DORMAA-AHENKRO IN THE BRONG AHAFO REGION OF GHANA)

BY

AMPOFO SAMUEL DATEH (PG 6316311)

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DECLARATION

I, Ampofo Samuel Dateh, declare that except for reference to other people's work, which have been duly cited, this submission is my own work towards Masters of Science Degree and that, it contains no material neither previously published by another person nor prescribed elsewhere.

Ampofo Samuel Dateh (PG6316311)	……………………	………………..
Name of student and ID	Signature	Date
Certified by	…………………...	………………..
Prof. S. K. Amponsah	Signature	Date
(Supervisor)		
Certified by	……………………	………………..
Prof. S. K. Amponsah	Signature	Date
(Head of Department)		
Certified by	……………………..	………………..
Prof. I. K. Dontwi	Signature	Date
(Dean, IDL)		

DEDICATION

I dedicate this work to my lovely wife Ms Debora Bonsu and my son Joel Awuku Ampofo.

ABSTRACT

The poultry industry has a significant importance on national economy. It is a popular industry for the small holders with tremendous contribution to gross domestic product (GDP) and employment creation. Poultry feed cost represents over sixty (60) percent of the total cost of poultry production; consequently efficient feed formulation practice is required for a sustainable poultry industry. Many Ghanaian poultry farmers, however, employ inefficient methods like rule of thumb, experiences, and intuition to handle feed formulation problem. The aim of this thesis is to develop an optimization feed formulation model, using locally available feed ingredients for the Ghanaian poultry industry. To achieve this aim, secondary data were collected from the recommended nutrient requirements schedule from Birds and Veterinary service, Ghana limited. Based on this data, linear programming model for least cost rations for broilers was formulated. Ten (10) decision variables and eight (8) constraints were identified. The optimal solution of the linear programming model for the least cost starter ration gives three (3) per cent reduction in broiler starter feed formulation as compared to the existing method on the farm whiles the optimal solution of the linear programming model for the least cost finisher ration also gives about three (3) per cent reduction in broiler finisher feed formulation compared to the existing method on the farm.

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CHAPTER ONE

1.0 Introduction

The livestock sector globally is highly dynamic. In developing countries, it is evolving in response to rapidly increasing demand for livestock products. In developed countries, demand for livestock products is stagnating, while many production systems are increasing their efficiency. Historical changes in the demand for livestock products have been largely driven by human population growth, income growth and urbanization. The production response in different livestock systems has been associated with science and technology as well as increases in animal numbers. In the future, production will increasingly be affected by feed and hence the need to blend the right amount of nutrients. Developments in breeding, nutrition and animal health will continue to contribute to increasing potential production and further efficiency and genetic gains. Livestock production is likely to be increasingly affected by feed. Demand for livestock products in the future could be heavily moderated by socio-economic factors such as human health concern and pricing of livestock products.

Livestock systems occupy about thirty (30) per cent of the planet's ice-free terrestrial surface area (Steinfeld et al., 2006) and are a significant global asset with a value of at least $1.4 trillion. The livestock sector is increasingly organized in long market chains that employ at least 1.3 billion people globally and directly support the livelihoods of six hundred (600) million poor smallholder farmers in the developing world (Thornton et al., 2006). Keeping livestock is an important risk reduction strategy for vulnerable communities, and livestock are important providers of nutrients and traction for growing crops in smallholder systems. Livestock products contribute seventeen (17) per cent to kilocalorie consumption and thirty-three (33) per cent to protein consumption globally, but there are large differences between rich and poor countries (Rosegrant et al., 2009).

Livestock systems have both positive and negative effects on the natural resource base, public health, social equity and economic growth (World Bank, 2009). Currently, livestock is one of the fastest growing agricultural subsectors in developing countries. Its share of agricultural Gross Domestic Product (GDP) is already thirty-three (33) per cent and is quickly increasing. This growth is driven by the rapidly increasing demand for livestock products, this demand being driven by population growth, urbanization and increasing incomes in developing countries (Delgado, 2005).

The global livestock sector is characterized by a dichotomy between developing and developed countries. Total meat production in the developing world tripled between 1980 and 2002, from forty-five to one hundred and thirty four (45 to 134) million tons (World Bank, 2009). In developed countries, on the other hand, production and consumption of livestock products are now growing only slowly or stagnating, although at high levels. Even so, livestock production and merchandizing in industrialized countries account for fifty-three (53) per cent of agricultural gross domestic product (World Bank, 2009). This combination of growing demand in the developing world and stagnant demand in industrialized countries represents a major opportunity for livestock keepers in developing countries, where most demand is met by local production, and this is likely to continue well into the foreseeable future. At the same time, the expansion of agricultural production needs to take place in a way that allows the less well-off to benefit from increased demand and that moderates its impact on the environment.

1.1 Background of the Study

1.1.1 Production

Human population in 2050 is estimated to be 9.15 billion, (UNDP, 2008). Most of the increase is projected to take place in developing countries. Rapid population growth could continue to be an important impediment to achieving improvements in food security in some countries, even when world population as a whole ceases growing sometime during the present century. Another important factor determining demand for food is urbanization. As of the end of 2008, more people now live in urban settings than in rural areas (UNFPA, 2008), with urbanization rates varying from less than thirty (30) per cent in sub-Saharan Africa to near eighty (80) per cent in developed countries. The next few decades will see unprecedented urban growth, particularly in Africa and Asia. Urbanization has considerable impact on patterns of food consumption in general and on demand for livestock products in particular, urbanization often stimulates improvements in infrastructure, including cold chains, and this allows perishable goods to be traded more widely (Delgado, 2005). A third driver leading to increased demand for livestock products is income growth. Between 1950 and 2000, there was an annual global per capita income growth rate of 2.1 per cent (Maddison, 2003). As income grows, so does expenditure on livestock products (Steinfeld et al., 2006). Economic growth is expected to continue into the future, typically at rates ranging from between 1.0 and 3.1 per cent (Vuuren et al., 2009). Growth in industrialized countries is projected to be slower than that in developing economies (Rosegrant et al., 2009).

Commercial poultry production in Ghana grew rapidly during the 1980-1990s, developing into a vibrant sector that supplied about eighty (80) per cent of the available chicken meat and eggs in the country. The development of the commercial poultry industry was initially slow, due to the irregular supply of imported day-old chicks, a lack of veterinary drugs and frequent outbreaks of poultry diseases. In order to increase growth, the Government of Ghana (GoG) removed customs duties on poultry inputs (feed, additives, drugs and vaccines) and improved access to veterinary services.

According to GoG sources, broiler production has experienced a steep decline from eighty (80) per cent of the market supply in 2000 to ten (10) per cent in 2010. This downward trend is due primarily to a very high cost of production (feed, drugs etc). Other constraints include the high energy prices which have pulled up production costs by over sixty (60) per cent. By 2005, commercial domestic poultry production was only able to meet thirty-four (34) per cent of total demand as most poultry producers shifted from producing broilers for meat to the production of eggs. Both GoG and industry sources have indicated that poultry meat (broiler) production for 2009/2010 fell to below ten (10) per cent of the demand. Most of the small and medium-scale producers completely shut down. Imported poultry products tend to be thirty (30) to forty (40) per cent cheaper than locally produced chicken. Ghana's current poultry layer count stands at twenty-one (21) million birds while broilers are at five million (National poultry census, 2009). Locally produced eggs face relatively minor competition on the Ghana market.

Although there was an outbreak of H5N1 avian influenza (AI) in May 2007, the disease was quickly contained by quarantining and destroying all the birds on the affected farms to stop the spread of the virus. To prevent further outbreaks of H5N1 AI, the GoG continues to do public awareness programmes in both print and electronic media (radio). Most large-scale commercial poultry farms have instituted high biosecurity measures to prevent the entry of poultry disease into their farms. A surveillance system has also been established by the GoG to monitor and assess the AI threat at all the entry points along the borders of Ghana, at market places and resting places of wild birds, including areas near water bodies. In addition training on detection and control of AI has also been carried out county wide for all veterinary officers of the Ministry of Food and Agriculture by USDA/APHIS.

Commercial poultry production in Ghana can be categorized into large-scale (over 10,000 birds), medium-scale (5,000-10,000 birds) and small-scale (50-5,000 birds) enterprises. Domestic commercial farms are privately owned by individuals or a family. The large-scale category forms about twenty (20) per cent of the total poultry sector, producing mainly eggs. Most operate their own feed-mill. The level of biosecurity practice is high in the large-scale category. The medium-scale and the small-scale categories comprise eighty (80) per cent of the poultry sector and rely on hatcheries for their day-old chicks and feed mills for their feed. The medium-scale category also produces primarily eggs. Included in the small-scale category are backyard poultry producers who mainly produce broiler birds. The medium and small-scale operators practice minimal biosecurity. This sometimes allows free-range and wild birds to gain access to these poultry houses, predisposing these operations to disease out-breaks such as AI. Some of the commercial poultry farmers produce broiler birds for sale only during the festive seasons (Christmas, Easter), periods when Ghanaians buy live chickens. Most of the poultry producers sell off spent layer chickens at these times.

Broiler and layer birds are kept exclusively indoors on deep litter and/or in battery cages, and fed on well formulated diets. The broiler birds attain 2.0-2.5 kg live-weight at six (6) to seven (7) weeks and are ready for the market. Layer birds reach sixteen (16) weeks before the pullets start laying eggs. Average industry egg production is two hundred and thirty to two hundred and fifty (230 to 250) eggs per layer per year. The main feed ingredients are locally produced corn or imported yellow corn, kernel cake, soya bean cake and fish meal; vitamin-mineral premixes are imported. According to industry sources, poultry production in Ghana is a high cost, intensive enterprise mostly due to the high input costs.

1.1.2 Feed Production

Ghana's poultry feed industry has shifted to producing layer feed due to the drop off in domestic broiler production. About ninety (90) per cent of feed produced by commercial feed millers is layer feed (National poultry census, 2009). Broiler feed is primarily purchased by small-scale backyard poultry producers. However, there is a seasonal feed demand from the larger producers who raise birds for the festive seasons such as Christmas and Easter.

The quality of ingredients used for feed production by a poultry feed milling facility is important because what birds eat can affect flock quality and the wholesomeness of a flock's meat and eggs. Most raw feed ingredients used as energy and/or a protein source in diets of poultry are grown, harvested, processed, and transported by someone outside of the poultry industry. Therefore, the ingredient quality control component of a poultry operation's feed mill is an important first step in preventing the contamination of birds on the farm.

Poultry feed accounts for about seventy (70) per cent of the total feed produced in Ghana. Feed manufacturers in Ghana can be categorized into commercial feed millers and on-farm self-millers. However, most feed millers are only producing at about forty (40) to fifty (50) per cent of their capacity due to the low demand from the local poultry industry. The average amount of compound feed produced in Ghana is about ten thousand (10,000) MT annually in the past few years. Commercial feed millers supply poultry feed mostly to medium and small-scale poultry producers because large-scale poultry producers mostly make their own feed. These commercial feed millers produce mainly mash feed while few produce high feed concentrates. Most small and medium-scale poultry producers prefer feed concentrates because it is cheap, convenient and less bulky for transportation. The main ingredients for compound feed are locally produced corn or imported yellow corn and wheat bran. Corn typically forms about fifty (50) to sixty (60) per cent of the total feed formulation (local farmers).

Modern intensive poultry production has achieved phenomenal gains in an efficient and economical production of high quality and safe chicken meat, eggs and poultry bi-products. At the same time as making gains in production and efficiency, the industry has to maximize the health and well-being of the birds and minimize the impact of the industry on the environment. The use of feed additives has been an important part of achieving this success.

The diet of animals and humans contain a wide variety of additives. However, in poultry diets these additives are primarily included to improve the efficiency of the bird's growth and/or laying capacity, prevent disease and improve feed utilization. Any additives used in feed must be approved for use and then used as directed with respect to inclusion levels and duration of feeding. The feed are also specific for the type and age of birds being fed.

Common feed additives used in poultry diets include antimicrobials, antioxidants, emulsifiers, binders, pH control agents and enzymes. Sometimes poultry diets will also contain other additives used in diets for humans and pets such as flavour enhancers, artificial and nutritive sweeteners, colours, lubricants, etc. In some instances additives are added to the animal's diet in order to enhance their value for human consumption, but mostly this is accomplished by use of natural ingredients containing significantly higher levels of these nutrients that can be deposited directly into meat and eggs (Australia chicken meat federation, 2002).

Growth promoting hormones are not used in the poultry industry. The efficient growth and egg productivity of commercial poultry has been achieved over the last fifty (50) years through traditional animal breeding techniques and improved nutrition and management (including health and housing) practices.

1.1.3 Nutrition

The science of nutrition involves providing a balance of nutrients that best meets the animal needs for growth, maintenance, egg production, etc. For economic reasons, this supply of nutrients should be at least cost, and so we must supply only enough for requirements, without there being any major excesses. It is very difficult and very expensive to supply all nutrients at the exact nutrient needs - rather we have to oversupply some nutrients in practical situations, in an attempt to meet the limiting nutrients. In poultry diets these limiting nutrients are usually energy and some of the essential amino acids, such as methionine and lysine.

Feed ingredients for poultry diets are selected for the nutrients they can provide to poultry, the absence of anti-nutritional or toxic factors, their palatability or effect on voluntary feed intake and their cost.

Poultry feed is made up of many ingredients, which are broadly grouped into providers of energy (fats, oils and carbohydrates), protein (amino acids), vitamins, minerals and product quality enhancement. Typically, cereals such as wheat, barley, sorghum and maize will provide energy while soya beans and peanuts provide protein. These ingredients are then combined in such a way as to provide the energy, protein, vitamin and mineral requirements for poultry through the process of feed formulation. In order to know what amounts of these ingredients should be included in the diet, the ingredients are first evaluated, to see what nutrients they contain and in what quantities. After the diet has been prepared, it may also be necessary to evaluate the complete product, to determine its suitability for the class of poultry that will be fed (such as egg layers, meat chickens or breeders) (Australia chicken federation, 2002).

The nutritional needs of farm animals with respect to energy, protein, minerals and vitamins have long been known, and these have been refined in recent decades.

Various requirement determination systems exist in different countries for ruminants and non-ruminants, which were originally designed to assess the nutritional and productive consequences of different feeds for the animal once intake was known. However, a large agenda of work still remains concerning the robust prediction of animal growth, feed requirements and production costs. Such work could go a long way to help improve the efficiency of livestock production and meeting the expectations of consumers and demands of regulatory authorities. Poor nutrition is one of the major production constraints in smallholder systems, particularly in Dormaa municipality.

Again, all ingredients and additives must be noted on the label and their use and inclusion levels meet the standards as defined by law. In some instances additives are added to the animal's diet in order to enhance their value for human consumption, but mostly this is accomplished by use of natural ingredients containing significantly higher levels of these nutrients that can be deposited directly into meat and eggs.

1.1.4 Diseases

Diseases are likely where larger numbers of birds are reared in confinement. A planned programme for the prevention and control of diseases in the poultry houses is a crucial factor in profitable poultry farming.

There has been tremendous growth in the global poultry industry over the past few decades. Some regions have reported a dramatic increase in the incidence of infectious disease outbreaks during this time of rapid expansion. In spite of the difficult challenges that the industry has been facing, poultry products (meat and eggs) still represent a major part of animal protein consumed by humans at the global level. Today's consumers are generally more health-conscious and react strongly to perceived safety issues associated with consumption of products of animal origin. In these days where the media tend to create hype rather than reporting the news, it is even more important to maintain a continuous vigilance to keep consumer confidence in poultry products. Maintaining the excellent health of poultry flocks is the primary objective of any producer since a healthy flock is usually a profitable flock. Despite all progress in prevention and control of infectious diseases, it is still difficult to keep a commercial poultry facility disease free. Commercial poultry farms continue to be affected by the emergence of new or variant disease agents. Diseases are generally responsible for mortality and reduced growth rate and egg production in poultry flocks. The end result of these diseases is reduced economic returns to producers. The emergence of new diseases and variants of existing diseases are becoming more common in the industry. Global trading and traveling have made it difficult to keep diseases to limited areas or regions.

Animal diseases generate a wide range of biophysical and socio-economic impacts that may be both direct and indirect, and may vary from localized to global (Perry and Sones, 2009). The economic impacts of diseases are increasingly difficult to quantify, largely because of the complexity of the effects that they may have, but they may be enormous.

The last few decades have seen a general reduction in the burden of livestock diseases, as a result of more effective drugs and vaccines and improvements in diagnostic technologies and services (Perry and Sones, 2009). At the same time, new diseases have emerged, such as avian influenza H5N1, which have caused considerable global concern about the potential for a change in host species from poultry to man and an emerging global pandemic of human influenza.

Appropriate sanitation and disinfection measures will help to prevent disease transfer from the old flock to the new one.

One of the key preventative measures for poultry diseases is proper sanitation. It is important to thoroughly clean empty rooms between flocks and remove any visible manure and dirt. All feeding, watering, and ventilation equipment should also be cleaned.

1.2 Statement of the Problem

With the exception of urban areas in Ghana, most poultry production in Ghana is undertaken through the extensive system at family level. This poultry provides a good source of protein and ready cash. The financial gains in turn help to sustain the family economy. However, this type of poultry production suffers from the constraints of feeding practice and overall production management which normally increase the production cost unduly. The production cost, is normally affected by managerial cost, labor cost, inventory cost, transportation cost, cost of drugs, housing and electricity, feeding cost, etc

However, it is established that the feeding cost alone takes about sixty to seventy (60-70) per cent of the total production cost, which is of major concern to the local farmers. The problem is recognized as optimizing factor, cost which depends on constraints (ingredients of the feed) and could be solved by deterministic linear programming model. This thesis seeks to do quantitative analysis of the poultry feed mix and thus develop a mathematical model for blending poultry feed mix to minimize the feeding cost in the poultry production.

1.3 Objective of the study

The main objectives of the study are:

(i) to do quantitative analysis of blending poultry feed mix

(ii) to formulate a linear programming model for minimizing the cost of blending poultry feed mix and

(iii) to carry out comparison between the existing practice and the parameters in the model of the poultry feed mix.

1.4 Justification of the study

The high cost of production is pushing poultry farmers out of business as the industry in Ghana is on the verge of collapse.

Currently, some factors such as unfair competition from the highly subsidized imported frozen dressed chicken, low purchasing power of consumers, high cost of feed and high interest rates charged by the commercial banks among other factors are hampering the growth of the sector.

This study focuses mainly on feed production in the poultry industry which is said to account for about sixty to seventy (60-70) per cent of the total cost in the whole poultry business. It will help to find a production model that will seek to reduce the cost of producing feed without compromising the required amount of nutrients needed in the feed mix.

1.5 Research Methodology

The feed formulation model seeks the optimum combination of available feed ingredients that will satisfy the nutritional requirements of the animal at the least cost possible. The model has to satisfy a set of constraints on nutritional levels, availability restrictions, special ingredients to be included, budget or fund constraints.

The following methods shall be used in other to achieve the objectives of the thesis.

These include the use of secondary data and the already published information relevant to the study shall be used, ie. journals, annual reports and the dailies. Linear programming model for minimizing blending feed mix cost for poultry production shall also be used. Sensitivity analysis on the ingredients (constraints) to find the effect of deficiency in any of the ingredients will be carried out. Matlab package of syntax linprog shall be used to solve and analyze the problem.

1.6 Significance of the Study

We need protein because “it has its hands in every critical function of the body”. About ten to thirty-five (10–35) per cent of calories comes from protein (Leslie Bonci, MPH, RD. 2011). Proteins are required for growth (especially important for children, teens, and pregnant women), tissue repair, immune function, making essential hormones and enzymes, energy when carbohydrate is not available and preserving lean muscle mass. Inadequate supply of protein year round due to high cost of production affects the livelihood of people depending on it.

Application of findings from this study will help reduce cost of producing poultry feed and eventually reduce cost of poultry products. This means that poultry birds and eggs will be affordable and so people will have the daily requirement of proteins the body needs.

Abundant of poultry products would earn the country more foreign exchange through exportation.

1.7Scope of the Study

The study aims at developing a blend feed mix model to minimize cost of poultry feed.

The formulation of feed mix model will seek the optimum combination of available feed ingredients that will satisfy the nutritional requirements of the animal at the least cost possible.

The work will intend to analyze the cost involved in feed production taking the minor seasons of maize (the most valuable ingredient in poultry feed) production in the year into account.

The study will not cover all aspects of poultry production, for instance managerial cost, labour cost, inventory cost and the cost of drugs.

1.8 Limitation of the Study

The major limitation encountered during the study was the reluctance of the farmers to give out information as to the main cost incurred in the feed production due to either poor book keeping or high rate of illiteracy.

1.9 Organization of the Study

In this chapter, we considered the background, problem statement and objective of the study. The justification, methodology, scope and limitation of the study were also put forward.

The remaining chapters will be structured as follows. Chapter two gives a review of the existing theoretical and empirical literature. Chapter three presents data collection, formulation of the mathematical model and the research methodology of the study. Chapter four is devoted for data collection and analysis. Chapter five, which is the concluding chapter of the study, presents conclusions and recommendations of the study.

1.10 SUMMARY

In this chapter, we considered the background, problem statement and objective of the study. The justification, methodology, scope and limitation of the study were also put forward.

In the next chapter, we shall put forward relevant literature on feed mix for poultry production and linear programming problem.

CHAPTER TWO

Literature Review

2.0 Introduction

In this chapter, we shall review the biggest single expense in any system of poultry production which is the feed accounting for up to seventy (70) per cent of total production cost per bird.

2.1 Food Competition and Food Production

Human population growth, urbanization and income improvements are causes of increased demands for foods of animal origin in the developing countries (Abdullah et al., 2011; Steinfeld, 2003). It is reviewed that shortages of animal protein availability is a problem in Africa (Mengesha, 2011). Based on this demands, there has been a rise in the production of foods of animal origin, particularly from poultry and pigs in the world. In this regard, FAO (2010) reported that contribution of poultry meat is around thirty-three (33) per cent of the total global meat production. However, this phenomena is not true for undeveloped countries in Africa, rather declining (FAO, 2011b; Kearney, 2010; Speedy, 2003; Delgado and Narrod, 2002).

Ethiopia has the highest number of livestock populations in Africa (Solomon et al., 2003). Out of which, poultry production plays an important role in rural livelihoods in Ethiopia (Thomas et al., 2009). However, rising demands for these products has led towards high prices (Ayele and Rich, 2010) of poultry products in a country. Poultry meat and egg production is the most environmentally efficient animal protein production systems (Mengesha, 2011; Van der Sluis, 2007) in the world. However, consumption of animal source food has always been low and declining as a result of the low production and the continuous growing of populations (FAO, 2005; UN, 2005) for sub-Saharan countries. Ethiopia's per capita consumption is declining overtime (FAO, 2005; Solomon et al., 2003). In contrast to this, the average world's meat consumption is doubled during this period (FAO, 2005).

It has been a common experience that with increased production of animal proteins, there is also increased demands for feeds, particularly for ingredients which have high protein and energy values. The contribution of protein and energy source ingredients is more than ninety (90) per cent of all required nutrients for poultry rations. Most ingredients of the poultry feeds are also used for human nutrition (Mengesha, 2011; John and Njenga, 1992) in east Africa that led for competition. These major poultry ingredients have been facing market competition with human food demands. Similarly, Gura (2008) reported that the competition between food, feed and agro-fuels is expected to aggravate prices of poultry feeds that enforce producers to look for alternative and locally available feed sources.

According to FAO (1995) reports, increment of mono-gastric animal production and the more intensive feeding systems with improved genotypes resulted in relatively greater demand for higher quality concentrate feeds. Moreover, mass production of pigs and poultry needs a larger proportion of the production of feed crops (Madan, 2005). As cereal products are increasingly used as feeds for animals, its share is projected to reach nearly forty-five to fifty (45-50) per cent by 2050 in the world (FAO, 2003).

Since feed is the main cost items in any system of poultry production, the beneficiaries of poultry development have been few in undeveloped countries (Reddy and Qudratullah, 1996). However, UNEP (2011) reported that chicken production is among the most energy-efficient sector in the world.

Information gap is clearly seen between issues of feed-food competition and the driving demands of foods of animal origin. Therefore, reviewing the essentials of feed-food competition and poultry production, in relation to producing animal-source foods for the driving demands is a prioritized issue that will help to look for alternative technologies. Moreover, reviewing the experiences of chicken production and its feed resource and thereby delivering summarized and synthesized information for beneficiaries is also another milestone to improve the production of poultry in the country.

2.2.0 Feed Production

In this section we shall review the demand of foods for poultry production.

2.2.1 Description of the Demands of Foods of Animal Origin

World Health Organization/Food and Agricultural Organization (WHO/FAO, 2003) reported that the economic development of a country is normally accompanied by improvements in a country's food supply and the gradual elimination of dietary deficiencies. Demands for animal sources foods, in developing countries have been progressively growing (Thornton, 2010). As Neumann and Harris (1999) reported, animal-source foods supply is not only high-quality and readily digestible protein and energy but are also a compact and efficient source of readily available micronutrients. According to Steinfeld (2003) reports, human population, urbanization and incomes improvements are the main causes to increase the demands for food of animal origin.

The overall increase of supply of animal product is restricted to certain countries and regions and is not an event for undeveloped sub-Saharan countries but is in declining phenomena. Speedy (2003) reported that the countries that consumes the least amount of meat per annum are found in sub-Saharan Africa and South Asia. However, as Jabbar et al., (2011) reported, rising global demands for animal products may be an offer of opportunities to the animal producers. In satisfying such enforced demands of foods of animal origins, the greatest increase is expected from poultry and pigs, as well as eggs and milk (FAO, 2011a; Speedy, 2003; Delgado and Narrod, 2002).

2.2.2 The Poultry Production Sector

Based on its level of bio-security and birds/products marketed, poultry production sector is classified as industrial, commercial, medium-commercial and village chicken productions systems (Rushton et al., 2004) in the world. Poultry production in developing countries is possibly described as a scavenging system (Kitalyi and Mayer, 1998). Kryger et al., (2010) reported also that approximately eighty (80) per cent of rural households in developing countries engage in smallholder poultry production (village systems). In sub-Saharan Africa, eighty-five (85) per cent of poultry sector is managed under village production systems (Sonaiya and Swan, 2004) and the species of chicken is the largest constituents of poultry population (Gueye, 2003; Yami, 1995) in Africa.

Around 97.82% of chicken production is traditionally managed (FAO, 2009). In this case, it is reported that the economy effects of shocks to this village system by HPAI outbreak are hypothesized to be small. Women and children are the most responsible groups of the households in managing village (Mengesha et al., 2008a; Mengesha and Tsega, 2011). Ayele and Rich (2010) reported that few intermediaries are existed in traditional poultry productions. The value chain for the traditional poultry sector is not as such complex. Moreover, Ayele and Rich (2010) reported that no public institutions are involved in importing, exporting, production, marketing and processing or in bio-security, particularly for small-scale producers of a country. Although, modern poultry farms are existed, their share of poultry production remains extremely small (Ayele and Rich, 2010; Thomas et al., 2009).

Annual poultry meat production in Ethiopia is increased by only 0.34%, on average while annual egg production declined by 0.39% (ILRI, 2000). But, Pica-Ciamarra and Otte (2009) reported that poultry has been the fastest growing sector than any animal farming in some other developing countries like for instance India. Of the supply and demand maps for animal-source foods to 2030, the most dramatic change is projected for poultry meat in South Asia (FAO, 2011b).

2.2.3 Socio-economics of Poultry Production

Food strategies must achieve the consumption of adequate quantities of safe and good quality foods (WHO/FAO, 2003). However, Speedy (2003) reported that wealth is the main determinant of per capita meat consumption. Technology is favoring the intensification of poultry production in developing countries (Mengesha, 2011), village poultry; still, is a profitable venture that contributing to the poverty alleviation and has no market problems. Moreover, Ayele and Rich (2010) reported from Ethiopia that most consumers are favouring to the traditional forms of chicken over processed products.

Women and children are responsible for caretaking of chicken and they are also beneficiaries in Ethiopia (Mengesha, 2011; Mengesha et al., 2008b). Chicken population as well as per capita consumption of egg and poultry meat has been declining to the face of population growth in a country. It is well reviewed that livestock production is likely to be increasingly affected by climate change; however, poultry industry has a relative advantage over the others because of its low global warming potential (Mengesha, 2011). However, Thomas et al., (2009) and Mengesha et al., (2011) reported from Ethiopia that poultry production is much lower than that of the fast-growing of the human population. In this case, Pica-Ciamarra and Otte (2009) advised that a public investment in support of backyard chicken farming development is important to enhancing nutritional status and employment.

Heft-Neal et al., (2008) reported from Thai that large scale industrial poultry production is one of the economy's most important sources of animal-derived food, employment and income.

2.2.4 Poultry Production and Food-Feed Competition

Global poultry industries have traditionally faced competition for feed ingredients from other animal industries (D'Souza et al., 2007; Hinrichs and Steinfeld, 2007). In this regards, D'Souza et al., (2007) reported that the growth of poultry consumption has been creating a huge gap of unavailability of feed grains to sustain poultry meat production. However, Hinrichs and Steinfeld (2007) reported that in the competition for the scarce feed resource, poultry has competitive advantages over other livestock as it has the best feed converters.

Although, poultry production has been the fastest growing sector than any animal farming in some developing countries (FAO, 2011a), its applicability is not achievable for those non grain self-sufficient countries.

Chadd (2007) reported that the feed versus fuel debate over cereal utilization set to be continuing controversy.

John and Njenga (1992) reported from Kenya that commercial poultry production will never be successful in Kenya until a steady supply of main feed ingredients. Substitution of grains in animal feeding systems goes a long way in resolving the food-feed competition. To design for sustainable feed resource utilization, well described information is required.

2.2.5 Poultry Feed Resources

The feed resources can be divided into two main categories as conventional and non-conventional feed resources. Conventional feed sources are those traditionally used. Whereas, those non-conventional once are not commonly and traditionally used as chicken feeds (Younas and Yaqoob, 2005). However, conventional feed resources are facing a problem of competition with human foods. Gura (2008) stated also that the recent feed price increment may upset many of the plans to further development of industrial livestock/poultry productions.

Anxiety on the alternative feed sources utilization is very likely to improve prices increments of poultry feeds. Consequently, FAO (2009) reported that smallholders, if not protected, may be among those who will suffer most from price increases in local feed sources. In this regard, Emam and Hassan (2010) reported from Sudan that the feed cost is the main cost item in different poultry-farm types and sizes.

While replacing alternative ingredients, equivalency of nutritional values, costs and side effects on birds should be assessed and considered. Gradual replacement or substitution of one type feeds or ingredients with the other is always advised to the producers that to adapting birds with such new feeds. The target of replacement of ingredients is always not to affecting the performances of birds.

Moreover, the trend of poultry production and the poultry feed source situation analysis is required for a country. Chadd (2007) reported that elevated levels of poultry feed availability will be required to meet feed demands of poultry production. Moreover, Chadd (2008) reported that if animals are part of an integrated farm production system, the overall energy efficiency can be actually increased through better utilization of organic wastes.

Feed is the most important input for poultry production and the availability of low-priced, high-quality feeds is critical for the expansion of the poultry industry and quality (FAO, 2003; Ismoyowati and Sumarmono, 2011).

Ravindran and Blair (1992) stated that the survival of the poultry industry in most developing countries, in the future will undoubtedly, depend on the ability of poultry industry to compete with humans for the available food supply. Energy market shocks will transmit into the feed market and increase market risk for poultry production (Hinrichs and Steinfeld, 2007).

Hendy et al (1995) suggested the composition of livestock populations and the intensity of feeding systems determine the mix of concentrate feeds required. Thus, increased mono-gastric animal populations and more intensive feeding systems with improved genotypes resulted in relatively greater demand for higher quality concentrate feeds.

Increments in poultry industry have a profound effect on the demands for feed and raw materials. The increasing cost and decreasing supply of traditional feedstuffs are expected to limit the future expansion of poultry production. This situation highlights the urgent need to improved utilization of the wide range of alternative feedstuffs available in these countries. Hendy et al., (1995) and Nweze et al., (2011) reported that changes in feeding systems will, however, be influenced by the needs to make the best use of resources available that can also lead to significant changes in demand for some feeds. According to John and Njenga (1992) reports, from Kenya that alternative programs must be initiated to encourage local production of main poultry feed ingredients.

There is a severe shortage of cereals and oilseed (cakes) for use in poultry feeds (Reddy and Qudratullah, 1996). Feed-food competition gives rise to looking for alternative feeds and other utilizing techniques to improving the nutritive values of poor ingredients (Reddy and Qudratullah, 1996; Mengesha and Abda, 2010; Mengesha, 2011). Haagsman et al., (2009) reported that the energy consumption of mankind is directly or indirectly used for food production, of which a considerable proportion is used for the production of meat.

According to the (Rosenzweig et al., 1993) reports, the effect of climate change on crop yields is more adverse. Due to climate change there is a consistent reduction of crop productivity, high market prices and malnutrition in Sub-Saharan Africa (Thompson et al., 2010). Chadd (2008) reported also that additional legislation will affects most aspects of the feed sectors.

Hendy et al., (1995) reported that the key factor that affects demands for feed commodities are human populations and incomes. Food-feed competition can be managed by substitution and correct pricing (Yotopoulos, 1987).

According to some reports, feed costs increments have override livestock prices and feed grain demands has been exceeding production. Therefore, utilization of those poor byproducts can be improved by various techniques; for instance solid state complex enzyme fermentation systems.

Most commonly used energy-rich feed stuffs in conventional poultry diet in Asia, Africa and Pacific nations has never been adequate for both human consumption and industrial uses (Reddy and Qudratullah, 1996). Thus, the higher the price of grains fed to animals the lower meat or eggs amount produced. In addition to increasing human population, a grain yield is also adversely affected by global warming that leads to food-feed competitions (Mengesha, 2011).

In this regard, Chadd (2008) reported that the genetic selection emphasis of recent times linked to nutrition, that of feed conversion efficiency and maximal growth potential. To improve the nutritional values of the feed resources of poultry, technology is required.

Some local poultry feed sources needs to be technically treated to improving nutritional values. As a result, these feedstuffs could be used as alternative feed source of poultry. Out of various techniques that have been used to improve poor feeds, some additives have nutritional values (e.g., amino acids) and others are without nutritive values (e.g., enzymes). The later group influences the nutritive value of a diet indirectly by improving the palatability of the diet, availability of ingredients, feed conversion and a healthy balance of the digestive tracts micro flora etc.

The availability of feed is the key factor that limits poultry production. A feed problem for poultry production in Ethiopia is not only the prices and availability but also their low quality. Therefore, the need to adapt feed additives that improves poultry feed utilization in the world may be another hot issue. In this regard, Chen et al., (1997) reported that the more effective and promising approaches to solve the problem of feed deficiency in poultry is utilization of additives.

Enzymes have several novel applications (Kumar et al., 2011) and some of them play critical role in the metabolic activities. Hence, feed enzyme supplementation has increased but predominantly in pig and poultry diets (Officer, 2000; Marquardt, 2000). Consequently, performances of egg production, egg mass and feed conversion by egg mass and egg dozen were better for those birds fed diets added with enzymes (Broz and Ward, 2007; Costa et al., 2008; Brenes et al., 1993). Although, there’s a genetic variation in performances and feed utilization efficiency in chickens (Egena et al., 2012; Ajayi, 2010; Zhang and Aggrey, 2003). Marks (1991) stated that the feed efficiency difference between genetically diverse stocks of chickens is small. Food-feed competition pushes to search for alternative feed ingredients like fibrous feeds as an energy source (D'Souza et al.,2007). Moreover, Hinrichs and Steinfeld (2007) reported that risk-mitigation strategies for capital-intensive poultry production will become increasingly important in order to cope up with market shocks.

Livestock production is likely to be increasingly affected by carbon constraints, environmental and animal welfare legislations (Thornton, 2010; Pant, 2011; Seo and Mendelsohn, 2006). However, poultry industry has a relative advantage over others due to its little warming potential (Mengesha, 2011; FAO, 2010; Costa, 2009); whereas, ruminants, are responsible for greenhouse gas emissions (Haagsman et al., 2009). Moreover, ILRI (2006) reported that the genetic diversity of indigenous chicken is much higher than other livestock species which have a good adaptability for climate and disease. In this regard, the desire for poultry meat and eggs without taboos and the relative ease in establishing poultry as an industry is driving forces at the movement (FAO, 2011c; Daghir, 2009).

According to FAO (2009) reports, chicken is usually the cheapest of all domestic livestock meats, particularly for sub-Saharan African and South Asian countries. Poultry meat and eggs are highly nutritious, cheapest, without taboos and efficient in feed utilization (Mengesha, 2011; Farrell, 2010; FAO, 2010). On the other hand, Costa (2009) reported that red meat industries have been pro-active in addressing environmental concerns. Poultry flocks; however, are also vulnerable to climate change because birds can only tolerate narrow temperature ranges. Although, poultry has relatively less effects, negative impact is still existed on the environment that due to employment of various production systems-intensive systems has less effect.

Having a lesser impacts on the environment and global warming than free-range production (FAO, 2010), intensive poultry production needs to be intensified to satisfying protein food demands (FAO, 2011c; Hinrichs and Steinfeld, 2007). Moreover, Steinfeld (2003) reported that livestock production and processing will become dominated by integrated large-scale commercial operations. Generally, Mengesha (2011) reported that upcoming animal-source food supply and demands will pose a challenge to the environment.

2.2.6 Consumption of Chicken Products and Human Health

Poultry products are preferred by consumers that these products provide foods with high-quality protein and a low level of fat with a desirable fatty acid profiles (FAO, 2010; Costa, 2009). It is well reviewed that there is a positive relationship between the level of income and the consumption of animal products (Mengesha, 2011).

ILRI (2000) reported that quality and safety considerations in foods of animal origin provide commercial opportunities for producers, market actors and industry participants of developing-countries.

Pisulewski (2005) also reported that consuming poultry and fish products has no risk of cancers. Furthermore, FAO (2003) also reported that the by-products of poultry production are of value if managed and recycled; however, if not managed or recycled properly are of concern.

2.2.7 Chicken Production and the Institutional Supports

To stimulate the rural economies, a proactive policy is required Steinfeld (2003) on behalf of the private and public sectors of the livestock production. However, there are no specific governance structures that established in Ethiopia for domestic production and marketing (Ayele and Rich, 2010). As to Muchenje et al., (2001) reports, poultry systems are bio-economically complex involving several kinds of resources and input/output flows that include crop-livestock components of the farming system.

According to the Adebayo and Adeola (2005) reports from Nigeria, gaps of poultry production need to be filled by the research and extension institutions to boosting egg and meat production. Sustainable cost effective interventions by the stakeholders are necessary to utilize local chicken potentials in Kenya (Njue et al., 2004). Sonaiya and Swan (2004) reported also that research and development institution must examine the social, cultural and technical constraints of family poultry.

According to Muchenje et al., (2001) reports; however, the economic importance of poultry is not adequately appreciated by researchers and decision-makers. Kryger et al., (2010) reported also that although poultry production is practiced by rural households, researchers and outsiders feel that its contribution to livelihoods is little nominal value. As Rodic et al., (2010) reported, from Syria although poultry is an important sector, it has no institutional support.

Poultry production has been given little attention by the research and development institutions in developing countries (Kryger et al., 2010; Scanes, 2007).

2.2.8 Biotechnology and the Production of Animal Feeds

Biotechnology in animal production has been advancing (FAO, 1991). Montaldo (2006) reported also that biotechnology is used to increase disease resistance, productivity and product quality in the economically important animals. Moreover, Chen (2001) reported that biotechnology will play critical role in the future in improving animal productivity. As to Peric et al.,(2009) reports, application of alternative growth promoters in nutrition of fattening chickens would be more efficient.

Since, adoption of animal biotechnology will results in a distinct benefits in prosperity, food security, rural development, animal improvement and economic returns to resource-poor farmers (Aboul-Naga and Elbeltagy, 2007; Chen, 2001), Aboul-Naga and Elbeltagy, (2007) advised to enhancing animal productivity and the sustainability through research focused applications of animal biotechnologies and their objectives. Advanced concept of biotechnology is still to making edible products from skeletal muscle cells, cultured from stem cells, outside the animal in a bioreactor (Haagsman et al., 2009).

According to some reports, biotechnology has the potential to improve the productivity of animals via increase growth, carcass quality and reproduction, improved nutrition and feed utilization, improved quality and safety of food. However, Aboul-Naga and Elbeltagy, (2007) reported that major constraints for applying animal biotechnologies, in near East and North African countries were summarized as: negligible investment in modern animal biotechnology. Aboul-Naga and Elbeltagy (2007) reported that Adoption of animal biotechnology will resulted in distinct benefits in prosperity, food security, rural development, animal improvement and economic returns to resource-poor farmers.

Although, livestock is predicted to become the most important agricultural sector in terms of growing and value-added commodity, this sector couldn’t satisfy the high demands of foods of animal origin. In some developing countries, chicken production has been the fastest growing sector than any animal farming that to supplying quality protein foods; however, the sector still is facing problems of feed-food competition and dependency for importation of improved breeds.

The advantage of socioeconomics of poultry productions is well documented in terms of family participation, easiness, nutritional values and environmental friendly but, development is lagging behind for sub-Saharan countries. Moreover, a main cost of poultry production is a concentrated feeds; hence, this sector has been facing a problem of feed-food competition, particularly for those non grain self-sufficient countries. Therefore, alternative feed resource should be properly utilized and the poor feeds also be improved by technologies for exclusive utilization.

Some local poultry feed resources needs to be technically treated to improving nutritional values that to be used as an alternative feed source. Therefore, modern technologies such as solid state fermentation complex enzyme systems and others must be increasingly important in order to cope up with market shocks.

Use of biotechnology in animal production has been advancing that quickly improving productivity and feed utilization. Moreover, advanced concept of biotechnology is still to making edible products from skeletal muscle-cells, cultured from stem cells, outside the animals. Therefore, policy makers need to facilitate its applicability in the future.

2.3.0 Important Considerations in Feed Formulation

Ration (or feed) formulation does not merely involve mathematical calculations to meet the requirement of the birds, since the result of the calculation may turn out to be impractical and not ideal for feeding of poultry. An experienced animal nutritionist, therefore, needs to evaluate the feed formulation before it can be given to the birds. Factors to be considered in making good feed formulations are:

2.3.1 Acceptability to the birds

The ration being formulated has to be palatable enough to stimulate intake by the birds. Feed refused by the birds is worthless, since feed has to be consumed and utilized by birds to serve its purpose.

2.3.2 Digestibility

The nutrients in the feed have to be digested and released into the gastrointestinal tract to be utilized by the birds. Rations with high fiber content cannot be tolerated by poultry.

2.3.3 Cost

The requirement of the birds can be met through several combinations of feed ingredients. However, when the costs of these ingredients are considered, there can only be one least-cost formulation. The least-cost ration should ensure that requirements of the birds are met and the desired objectives are achieved.

2.3.4 Methods of Formulating Rations

There are several methods in formulating rations. All of them have the same objectives of providing the required balanced nutrients at the least possible cost.

2.3.5 Trial-and-error Method

This is the most popular method of formulating rations for poultry. As the name implies, the formulation is manipulated until the nutrient requirements of the birds are met. This method makes possible the formulation of a ration that meets all the nutrient requirements of the birds.

2.3.6 Components of Poultry Diets

Poultry diets are made primarily from a mixture of several feedstuffs such as cereal grains, soya bean meal, animal by-product meals, fats and vitamin and mineral premixes (Longe, 1984; Alimon and Hair-Bejo, 1995). A poultry diet is expected to contain three essential nutrients of protein, vitamins, and minerals as well as provides adequate metabolizable energy (ME). Energy is very critical in poultry feed, in fact, the more the energy loaded in the ration, the less feed the birds would consume (Larbeir and Leclercq, 1994). The most easily available sources of energy are the carbohydrates contained in common grains, grain by-products and plants generally. Most of the carbohydrate in poultry diets is provided by cereal grains. Suitable quantities of fat may be added to increase dietary energy concentrations and palatability. Protein is essential in all animal life. Proteins make up a large part of the muscle, skin, beak, feathers, cartilage and internal organs of animals and are needed for growth, egg production, reproduction, production of antibodies to fight diseases, etc. The dietary requirement for protein is actually a requirement for amino acids. Specific amino acids must be provided in proper amounts and in some definite ratios to others. An undersupply of a single essential amino acid will inhibit the responses to those in adequate supply (Alimon and Hair-Bejo, 1995; Fanatico, 2010). In any protein, the limiting amino acid is the one which is below the standard.

For poultry, methionine is usually the first limiting amino acid and lysine the second limiting amino acid. Since protein is not stored in the body to any considerable extent, any protein consumed above the birds' requirement is oxidized for energy. However, since protein sources are expensive and uneconomic for energy provision protein levels are usually stated in precise terms to be closer to the minimum requirement than other nutrients. Protein sources can be of a plant origin such as soya and groundnut cake or of an animal origin, such as fish meal. Some sources of minerals include Oyster shell and limestone which are both rich in calcium.

Bone meal is a very good source of both calcium and phosphorus amongst others. Common salt can satisfy the birds' sodium and chloride requirements. However trace mineral requirements are usually met by supplementation via the vitamin/mineral premix (Scheideler, 2009).

2.4 Modeling using Linear Programming

In this section we shall present the theory of LP and its models.

2.4.1 Optimization Model

Communal farmers are usually faced with the problem of how to allocate their limited production resources among cropping and livestock activities. These farmers always seek an optimal mix of farming activities that maximizes their income. Farmers, often, follow their instinct and experience to handle this problem. Hazel and Norton, (1986) also say, traditionally, farmers have relied on experience, intuition and comparisons with their neighbours to make their decisions. Instinct and experience do not guarantee optimal results; however, farm planners can offer effective techniques, such as, linear programming (LP), to address such a problem and produce optimal solutions. Alsheikh and Ahmed, (2002) demonstrated how LP can be used as a tool to obtain optimal results. Their application of LP as a tool for farm resource allocation created an initial basis for this study.

Businesses have saved thousands of millions of dollars by using LP. Annetts and Audsley (2002) developed an LP model to consider a wide range of farming situations, which allows optimization of profit or environmental outcome(s) or both. The modelling considered the problem of planning a farming system within a world where environmental considerations are increasing. Their objective was to identify the best cropping and machinery options which are profitable and result in improvements to the environment, depending upon the farm situation of market prices, potential crop yields, soil and weather characteristics. The results showed that large reductions in environmental impact can be achieved for reductions in farm profit which are insignificant relative to the annual variation due to yields and prices. Mohamad and Said, (2001) developed an LP crop mix model for a finite-time planning horizon. Given limited available resources such as budget and land acreage, the crop-mix planning model was formulated and transformed into a multi-period linear programming problem. The objective was the maximization of the total returns at the end of the planning horizon

2.4.2 Developing LP Models

A problem consisting of a linear function of variable called objective function subject to set of linear equation or inequalities called constraints are known as linear programming problem.

It is well established that many business problems, such as supply chain management, production planning, scheduling, workflow management can be solved using mathematical methods. With the technological advancements, mathematical modeling is playing a significant role in solving complex business problems.

2.4.3 Decision Variables

To develop any mathematical model, we start by defining the decision variables. A decision variable is a controllable input variable that represents the key decisions a manager must make to achieve an objective. We denote these by the variables $x_1, x_2, x_3, \dots x_n$.

2.4.4 Objective Function

Every linear programming problem has a specific objective. If a company makes \$2 for every 40-pound bag produced, it will make $2x_1$ dollars if it produces x_1 40-pound bags. Similarly, if it makes \$4 for every 80-pound bag produced, it will make $4x_2$ dollars if it produces x_2 80-pound bags. Denoting total profit by the symbol z, and dropping the dollar signs for convenience, we have Total profit$z = 2x_1 + 4x_2$. Note that total profit is a function of the decision variables; thus, we refer to $2x_1 + 4x_2$ as the objective function. The constant terms in the objective function are called objective function coefficients. Any particular combination of decision variable is referred to as a solution. Solutions that satisfy all constraints are referred to as feasible solutions. Any feasible solution that optimizes the objective function is called an optimal solution.

2.5 Application of Linear Optimization

In this section we shall discuss some application of linear programming.

2.5.1 Transportation Problem

The transportation problem is a special type of linear program that arises in planning the distribution of goods and services from several supply points to several demand locations. Usually the quantity of goods available at each supply location (origin) is limited, and a specified quantity of goods is needed at each demand location (destination). With a variety of shipping routes and differing transportation costs for the routes, the objective is to determine how many units should be shipped from each origin to each destination so that all destination demands are satisfied with a minimum total transportation cost.

The Transportation Problem was one of the original applications of linear programming models. A firm produces goods at m different supply centers. Label these $i = 1, \dots, m$. The supply produced at supply center i is S_i. The demand for the good is spread out at n different demand centers. Label these $j = 1, \dots, n$. The demand at the j^{th} demand center is D_j . The problem of the firm is to get goods from supply centers to demand centers at minimum cost. Assume that the cost of shipping one unit from supply center i to demand center j is C_{ij} and that shipping cost is linear. That means that if you shipped X_{ij} units from supply center i to demand center j, then the cost will be $C_{ij}X_{ij}$. Define X_{ij} to be the number of units shipped from supply center i to demand center j. The problem is to identify the minimum cost of shipping schedule. The constraints are that you must (at least) meet demand at each demand center and cannot exceed supply at each supply center. The cost of the schedule, by the linearity assumption is given by $\min \sum_{i=1}^{m} \sum_{j=1}^{n} X_{ij} C_{ij}$. The total amount shipped out of supply center i is $\sum_{j=1}^{n} X_{ij}$. X_{ij} is what you shipped from i to j. From i you can ship to any demand center $j = 1, \dots, n$. The sum above just add up to the total shipment from center i. This quantity cannot exceed the supply available. Hence we have the constraints $\sum_{j=1}^{n} X_{ij} \leq S_i$ for all $i = 1, \dots, m$.

Similarly, the constraints that guarantee that you meet the demands at each of the demand centers is $\sum_{i=1}^{m} X_{ij} \leq D_j$ for $j = 1, \dots, n$.

The only way that the problem can be feasible is if total supply exceeds total demand

$\sum_{j=1}^{n} D_j \leq \sum_{i=1}^{m} S_i$. If this equation does not hold, then there would be excess demand. There would be no way to meet all of the demand with available supply. If there is enough supply, then you should be able to convince yourself that you can satisfy the constraints of the problem. That is, the problem is feasible unless there is excess demand.

It is conventional to assume that the total supply is equal to the total demand.

If so, that is, if $\sum_{j=1}^{n} D_j = \sum_{i=1}^{m} S_i$, then all of the constraints in the problem must hold as equations (that is, when total supply equals total demand, then a feasible transportation plan exactly meets demand at each demand center and uses up all of the supply at each supply center). (In cases where there is excess supply, you can transform the problem into one in which supply is equal to demand by assuming that you can freely dispose of the extra supply.)

After making the simplification that total supply equals total demand, we arrive at the standard formulation of the transportation problem. The problem provides m supplies S_i for $i = 1, \dots, m$,n demands D_j for $j = 1, \dots, n$ that satisfy $\sum_{j=1}^{n} D_j = \sum_{i=1}^{m} S_i$, and costs C_{ij}. The objective is to find a transportation plan denoted by X_{ij} to solve:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} X_{ij} C_{ij}$$

subject to

$\sum_{j=1}^{n} X_{ij} = S_i$ for all $i = 1, \dots, m$.

and

$\sum_{i=1}^{m} C_{ij} = D_j$ for all $j = 1, \dots, m$.

In this problem it is natural to assume that the variables X_{ij} take on integer values (and non-negative ones). That is, you can only ship items in whole number batches.

2.5.2 Blending Problem

Blending problems arise whenever a manager must decide how to combine two or more ingredients in order to produce one or more products. These types of problems occur frequently in the petroleum industry (such as blending crude oil to produce different octane gasoline) and the chemical industry (such as blending chemicals to produce fertilizers, weed killers, and so on). In these applications, managers must decide how much of each resource to purchase in order to satisfy product specifications and product demands at minimum cost.

When testing products to find the best blend product configuration, there are particular problems encountered for certain product parameters. It is difficult to find the best blend product parameters when the product is a "blend".

2.6 Summary

In this chapter, relevant literatures pertaining to this work were reviewed. The theory of optimization and its model as well as some applications of LP model were also discussed.

In the next chapter, we shall present the research methodology of the study.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

In past, producers balanced rations by hand calculation, often using long tedious trial-and-error methods. But in the past two decades, industries have adapted computers to every conceivable task, and the feed industry is no exception.

Feed formulation is a process by which different feed ingredients are combined in a proportion necessary to provide the bird with proper amount of nutrients needed at a particular age/stage of production. It requires the knowledge about nutrients, feedstuffs and nutritional requirement of the birds in the development of nutritionally adequate rations that will be eaten in sufficient amounts to provide the level of production at a reasonable cost. The ration should be palatable and will not cause any serious digestive disturbance or toxic effects to the birds.

Different classes of birds have different requirements for energy (carbohydrates and fats), proteins (amino acids), minerals and vitamins in order to maintain its various functions like growth, reproduction and egg production. Formulation of rations for poultry emphasizes the use of linear programming using a computer to derive the least-cost ration.

It is imperative for poultry producers to source for cheap alternative feedstuffs without affecting the quality of the feed, productive performance of the birds and the economics of production. One of the major problems facing poultry producers is high prices and non-availability of feed ingredients. Availability of quality feed at a reasonable cost is a key to successful poultry operation (Hooge and Rowland, 1978). Linear programming is one of the most important techniques to allocate the available feedstuffs in a least cost broiler ration formulation (Dantzig, 1951a, b; Aletor, 1986; Ali and Leeson, 1995).

3.1 Theory of Linear Programming (LP)

This is a method of determining the least-cost combination of ingredients using a series of mathematical equations. There are many possible solutions to each series of equations, but when the factor of cost is applied, there can only be one least cost combination.

An electronic computer is capable of making thousands of calculations in a very short time. However, the machine is incapable of correcting errors resulting from incorrect data and errors in setting up of the program. Therefore, the resultant rations obtained from linear programming will be no better than the information and values which are entered into the programming.

Linear Programming (LP) is a technique for optimization of a linear objective function, subject to linear equality and linear inequality constraints (Kuester and Mize, 1973). Informally, linear programming determines the way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model and given some list of requirements represented as linear equations. Patrick and Schaible, (1980) stated that linear programming is technically a mathematical procedure for obtaining a value-weighting solution to a set of simultaneous equations. Linear programming was first put into significant use during World War II when it was used to determine the most effective way of deploying troops, ammunitions, machineries which were all scarce resources (ChvÂ´atal, 1983). There are hundreds of applications of linear programming in agriculture (Taha, 1987). Olorunfemi et al., (2001) reviewed extensively the use of linear programming in least cost ration formulation for aquaculture. Olorunfemi et al., (2001) also applied linear programming into duckweed utilization in least-cost feed formulation for broiler starter.

3.2 Optimization Model

Quantitative models that seek to maximize or minimize some objective function while satisfying a set of constraints are called optimization models. An important category of optimization models is Linear Programming (LP) models, which are used widely for many types of operations design and planning problems that involve allocating limited resources among competing alternatives, as well as for many distribution and supply chain management design and operations. The term programming is used because these models find the best "program," or course of action, to follow. An LP model can be developed to find the best mix of products to meet demand and effectively use available resources. A manufacturer might use an LP model to develop a production schedule and an inventory policy that will satisfy sales demand in future periods while minimizing production and inventory costs, or to find the best distribution plan for shipping goods from warehouses to customers. Services use LP to schedule their staff, locate service facilities, and minimize the distance traveled by delivery trucks and school buses.

3.3.0 Definition and Standard forms of LP

Corresponding to any giving linear programming problem, called the primal problem, there is another linear programming problem called the dual problem. Since a giving linear programming problem can be stated in several forms (standard form, canonical form, general form etc). It follows that the form of the dual problem will depend on the form of the primal problem.

We say that an LP is in standard form if its matrix representation has the form

Max. $C^T X$, ie. It must be a maximization problem.

s.t. $AX \leq b$, ie. Only inequalities of the correct direction.

$0 \leq X$, ie All variables must be non-negative.

Where X represents the vector of variables (to be determined), C and b are vectors of (known) coefficients, A is a (known) matrix of coefficients and $(.)^T$ is the matrix transpose. The expression to be maximized or minimized is called the objective function. The inequalities are the constraints which specify a convex polytope over which the objective function is to be optimized.

We point out that every linear program can be converted into standard form

Max $c_1x_1 + c_2x_2 + \cdots + c_nx_n$

s.t $a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = b_1$

$a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n = b_m$

$x_1 \geq, \ldots, x_n \geq 0$

Where the objective is maximized, the constraints are equalities and the variables are all non negative.This is done as follows:

i. If the problem is min z, convert it to max -z.

ii. If a constraint is $a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n \leq b_i$, convert it into an equality constraint by adding a nonnegative slack variable s_i. The resulting constraint is $a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n + s_i = b_i$, where $s_i \geq 0$.

iii. If a constraint is $a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n \geq b_i$, convert it into an equality constraint by subtracting a nonnegative surplus variable s_i. The resulting constraint is $a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n - s_i = b_i$, where $s_i \geq 0$.

iv. If some variable x_j is unrestricted in sign, replace it everywhere in the formulation by $x_j^{'} - x_j^{''}$

where $x_j^{'} \geq 0$ and $x_j^{''} \geq 0$.

3.3.1 Solution Techniques of LP

There are several approaches for solving the LP problems. Among these techniques are:

i) Graphical approach

ii) Simplex Algorithm

iii) QSB package

iv) Matlab package

v) YE'S Interior Point algorithm

vi) Microsoft Excel 2003

The most convenient and effective techniques in use now is the simplex algorithm. The detail discussion of the simplex is given below.

3.3.2.0 The Simplex Method

It is a systematic way of examining the vertices of the feasible region to determine the optimal value of the objective function. Simplex usually starts at the corner that represents doing nothing. It moves to the neighbouring corner that best improves the solution. It does this over and over again, making the greatest possible improvement each time. When no more improvements can be made, the most attractive corner corresponding to the optimal solution has been found.

3.3.2.1 The Standard Maximum form for a Linear Program

A standard maximum problem is a linear program in which the objective is to maximize an objective function of the form:

$$Z = C_1X_1 + C_2X_2 + ... + C_nX_n$$

subject to:

$$a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n \leq b_1$$

$$a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n \leq b_2$$

$$.$$

$$.$$

$$a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n \leq b_m$$

where $x_1, x_2, ..., x_n \geq 0$

and $b_j \geq 0$ for $j = 1, 2, ..., m$

3.3.2.2 The Simplex Tableau

To set up the simplex tableau for a given objective function and its constraints, add none negative slack variable s_i to the constraints. This is to convert the constraints into equations. The constraints therefore become:

$$a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n = b_1$$

$$a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n = b_2$$

$$.$$

$$.$$

$$a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n = b_m$$

where $x_i \geq 0$ for $i = 1, 2, ..., n$

Table 3.1; shows table for formulating simplex tableau

	c_j	c_1	c_2	$\cdots$	c_n	0	0	$\cdots$	0	
C_B	B. V.	x_1	x_2	$\cdots$	x_n	s_1	s_2	$\cdots$	s_n	RHS
0	s_1	a_{11}	a_{12}	$\cdots$	a_{1n}	1	0	$\cdots$	0	b_1
0	s_2	a_{21}	a_{22}	$\cdots$	a_{2n}	0	1	$\cdots$	0	b_2
.	.	.	.		.	.	.		.	.

. .	. .	. .	. .		. .	. .	. .		. .	. .
0	s_m	a_{m1}	a_{m2}	$\dots$	a_{mn}	0	0	$\dots$	1	b_m
	z_j	0	0	$\dots$	0	0	0	$\dots$	0	0
	$c_j - z_j$	c_1	c_2	$\dots$	c_n	0	0	0	0	

C_B is the objective function coefficients for each of the basic variables.

Z_j is the decrease in the value of the objective function that will result if one unit of the variable corresponding to the j^{th} column of the matrix formed from the coefficients of the variables in the constraints is brought into the basis (thus if the variable is made a basic variable with a value of one).

$C_j - Z_j$ called the Net Evaluation Row, is the net change in the value of the objective function if one unit of the variable corresponding to the j^{th} column of the matrix (formed from the coefficient of the variables in the constraints), is brought into solution.

From the $C_j - Z_j$ row we locate the column that contains the largest positive number and this becomes the Pivot Column. In each row we now divide the value in the RHS by the positive entry in the pivot column (ignoring all zero or negative entries) and the smallest one of these ratios gives the pivot row. The number at the intersection of the pivot column and the pivot row is called the PIVOT.

We then divide the entries of that row in the matrix by the pivot and use row operation to reduce all other entries in the pivot column, apart from the pivot, to zero.

3.3.2.3 The Stopping Criterion

The optimal solution to the linear program problem is reached when all the entries in the net evaluation row, that is, $C_j - Z_j$, are all negative or zero.

3.3.2.4 Minimizing the Objective Function

Standard form of LP problem consists of a maximizing objective function. Simplex method is described based on the standard form of LP problems. If the problem is a minimization type, the objective function is multiplied through by – 1 so that the problem becomes maximization one.

$$\text{Min } F = -\text{ Max } F$$

3.3.4.5 Constraints of the $\geq$ Type

The LP problem with 'greater-than-equal-to' ($\geq$) constraint is transformed to its standard form by subtracting a non-negative surplus variable from it:

$$a_i x \geq b_i$$

is equivalent to $a_i x - s_i = b_i$ and $s_i \geq 0$, where s is called surplus.

3.3.2.6 Equality Constraint

Situation where any of the constraints is of the linear programming is of the form:

$$a_1x_1 + a_2x_2 + ... + a_nx_n = b,$$

The single constraint is replaced with the following two constraints:

$$a_1x_1 + a_2x_2 + ... + a_nx_n \le b \text{ and } a_1x_1 + a_2x_2 + ... + a_nx_n = b.$$

The usual procedure is then applied.

3.3.2.7 Sensitivity analysis of LP

However, due to conditions such as unstable market prices, post optimality analysis is required to ascertain the effects and economic implications of the price changes on the formulation. While optimal solutions simply provide a best choice of decision variables for one fixing of the input parameters, sensitivity analysis then tries to complete the picture by studying how results would vary with change in parameter values (Arsham, 2009; Rardin,1998). The constant parameters from which the optimum was derived such as costs, yields, availability and requirements are almost never known with certainty at the time the model is solved. The extent to which these mathematically optimal answers can be trusted to real life imperfectly parameterized models is questionable. For instance, it is a usual occurrence to have seasonal fluctuations in the price of feed ingredients. It is common for the market price of feed ingredients to rise during the rainy season and fall back during the dry season when there is an abundance of dry grains. Hence post optimality was carried out on the model.

The discussion relates to help LP problem in standard form. That is

Max $C^T X$ or Min $C^T X$ (3.1)

s.t Ax=b Ax=b (3.2)

x≥0 x≥0 (3.3)

Sensitivity analysis is based on the information available to us through the optimal simplex tableau. Such a tableau satisfies both the feasibility conditions and the optimality conditions. Satisfying the feasibility means that the relations (3.2) and (3.3) are satisfied. Satisfying the optimality conditions means that the reduced cost g_j for all non-basic variables (rate of change of the objective function with respect to the non-basic variable) are non-positive if we are maximizing and non-negative we are minimizing.

3.3.2.8 Applications of LP

Linear programming can be applied to various fields of study. It is used in business and economics, but can also be utilized for some engineering problems. Industries that use linear programming models include transportation, energy, telecommunications and manufacturing. It has proved useful in modeling diverse types of problems in planning, routing, scheduling, assignment and design.

3.4.0 Proposed LP Model

Mathematical models were constructed for starter and finisher types of broiler ration using limited ingredients. The objective of the models was to minimize cost of producing a particular diet after satisfying a set of constraints. These constraints were mainly those from nutrient requirements the bird and ingredient constraints (Harper and Lim, 1982). The variables in the models were the ingredients while the cost of each ingredient and the nutrient value of each ingredient was the parameter (Hillier and Lieberman, 1995). The specified LP model for the attainment of the objective function is:

Minimize $Z = \sum C_{ij} X_j$

where:

Z = Total cost of the ration

C_j = Ingredient cost, $j = 1,2,3,\dots,m$

X_i = Ingredient quantity, $i = 1,2,3,\dots,n$

Subject to the following constraints:

$x_1 + x_2 + x_3 + \cdots + x_8 = b_1$

$a_{11}x_1 + a_{12}x_2 + \cdots + a_{18}x_8 \le b_2$

$a_{21}x_1 + a_{22}x_2 + \cdots + a_{28}x_8 \le b_3$

$a_{31}x_1 + a_{32}x_2 + \cdots + a_{38}x_8 \le b_4$

$a_{41}x_1 + a_{42}x_2 + \cdots + a_{48}x_8 \le b_5$

$a_{51}x_1 + a_{52}x_2 + \cdots + a_{58}x_8 \le b_6$

$a_{61}x_1 + a_{62}x_2 + \cdots + a_{68}x_8 \le b_7$

$a_{71}x_1 + a_{72}x_2 + \cdots + a_{78}x_8 \le b_8$

$a_{81}x_1 + a_{82}x_2 + \cdots + a_{88}x_8 \le b_9$

$a_{91}x_1 + a_{92}x_2 + \cdots + a_{98}x_8 \le b_{10}$

$a_{101}x_1 + a_{102}x_2 + \cdots + a_{108}x_8 \le b_{11}$

$x_i \geq 0, i = 1,2,3, \ldots, n$

where:

a_i = Technical coefficients of nutrient components in feedstuffs

b_i = Constraints of the ration

3.4.1 Assumptions

Before a valid result can be obtained from linear programming technique, the following assumptions must be holding:

(i) Linearity: There must be a linear relationship between the output and the total quantity of each resource consumed. If the objective function is not linear, the technique will not be applicable (Dantzig, 1955).

(ii) Simple objective: The objective can either be maximization or minimization of one activity.

(iii) Certainty: All values and quantities must be known with certainty.

(iv) Additivity: This means that the sum of resources used by different activities must be equal to the total quantity of the resources used by each activity for all the resources (Dantzig, 1963).

(v) Divisibility: Perfect divisibility of outputs and resources must exist.

(vi) Non-negativity: Decision variables cannot be added to the final objective function in a negative way. That is each of the decision variables must either be positive or zero.

(vii) Finiteness: The constraints and the variables must be finite so that it can be programmed. Hence, a finite number of activities and constraints must be employed (Gale et al., 1951).

(viii) Proportionality: This implies that the contribution of each variable to the final objective function is directly proportional to each variable. If we want to double the output then all decision variables must be doubled.

3.4.2 General remarks

There are three assumptions within the feed formulation problem. First, the nutrient requirements are assumed constant and independent of the final product (e.g., livestock) price. Second, the quality of each feed ingredient is known. Third, the diet is assumed to depend on only feed price and nutrients.

The diet problem is widely used, especially in formulating feed rations. Animal scientists use the term "ration-balancing", and several software programs have been specifically developed to determine least cost rations. LP models of the ration problem were used by Prevatt, et al., to evaluate fed cattle production in Florida and by Thomas et al. (1992) who examined nutrient values in dairy production.

3.5.0 General Optimization Algorithm

(1) Given an iterate x^k, find the search direction Δx by solving the linear system

$\nabla f(x^k)\Delta x = -f(x^k)$.

(2) Find the step size α_k.

(3) Update x^k to $x^{k+1} = x^k + \alpha_k \Delta x$.

The symbol ∇f represents the derivative, gradient, or Jacobian of the function f depending on the definition of the function f.

3.5.1 Starting Point

The choice of starting point depends on two requirements: the centrality of the point and the magnitude of the corresponding infeasibility. These conditions are met by solving two least squares problems which aim to satisfy the primal and dual constraints:

$$\min_{x} x^T x \ s.t \ Ax = b$$

$$\min_{(y,s)} s^T s \ s.t \ A^T y + s = c$$

These problems have solution:

$$\tilde{x} = A^T (AA^T)^{-1} b, \quad \tilde{y} = (AA^T)^{-1} Ac, \quad \tilde{s} = c - A^T \tilde{y}$$

The solution is further shifted inside the positive orthant to obtain the starting point as:

$$w^o = \left(\tilde{x} + \delta_x e, \tilde{y}, \tilde{s} + \delta_s e\right),$$

where δ_x and δ_s are positive quantities.

3.5.2 Search Direction

It is $(\Delta x, \Delta y, \Delta z)$. It is obtained by solving the Newton's equation:

$$\nabla f(x,y,s) \begin{bmatrix} \Delta y \\ \Delta x \\ \Delta s \end{bmatrix} = -f(x^k, y^k, s^k)$$

3.5.3 Step Size

The choice of step-size is essential in proving good convergence properties of interior point methods.

The step size is chosen so that the positivity of x and s are preserved when updated. $\alpha^{\max}$ is the maximum step size that is chosen until one of the variables becomes zero (0).

$\alpha^{\max}$ is calculated as follows:

$$\alpha_P^{\max} = \min\left\{-\frac{x_i}{(dx)_i} : (dx)_i < 0, i = 1,...,n\right\},$$

$$\alpha_D^{\max} = \min\left\{-\frac{s_i}{(ds)_i} : (ds)_i < 0, i = 1,...,n\right\},$$

$$\alpha^{\max} = \min\left\{\alpha_P^{\max}, \alpha_D^{\max}\right\}.$$

Since none of the variables is allowed to be zero (0), $\alpha = \min\{1, \theta\alpha^{\max}\}$ is taken, where $\theta \in (0,1)$ The usual choice is $\theta = 0.9$ or $\theta = 0.95$.

3.5.4 Termination Criteria

Due to the presence of the barrier term that keeps the iterates away from the boundary, they can never produce and exact solution. Feasibility and complementarity can therefore be attained only within a certain level of accuracy.

For these reasons, termination criteria for the algorithm to be used have to be decided on. Some common termination criteria used in practice are as follows:

$$\frac{\|Ax-b\|}{1+\|x\|_\infty} \le 10^{-p}, \qquad \frac{\|A^T y+s-c\|}{1+\|s\|_\infty} \le 10^{-p}, \qquad \frac{|c^T x-b^T y|}{1+|b^T y|} \le 10^{-q}.$$

The values of p and q required depend on the specific application.

3.5.5 Primal Dual Methods

It is one of the three main categories of the interior point methods. The primal dual algorithm operates simultaneously on the primal and the dual linear programming. They find the solutions (x^*, y^*, s^*) of

$$\begin{bmatrix} A & 0 & 0 \\ 0 & A^T & I \\ S^k & 0 & A^k \end{bmatrix} \begin{bmatrix} d_x \\ d_y \\ d_s \end{bmatrix} = \begin{bmatrix} r_P^k \\ r_D^k \\ -X^k s^k + \gamma\mu_k e \end{bmatrix}$$

by applying variants of Newton's method to the above and modifying the search directions and the step lengths so that inequalities $(x,s) \ge 0$ are satisfied strictly at every iteration. $X, S \in R^{n\times n}$ are diagonal matrices of x_i, s_i respectively and $e \in R^n$ is a vector of ones.

3.5.6 The Primal Problem

Given the linear programming problem in the standard form:

(P) minimize $c^T x$

subject to $Ax = b$, $x \ge 0$

where $c \in R^n$, $A \in R^{m\times n}$ and $b \in R^m$ are given data, and $x \in R^n$ is the decision variable.

The dual (D) to the primal (P) can be written as:

(D) maximize $b^T y$

subject to $A^T y + s = c$, $s \geq 0$

with variables $y \in R^m$ and $s \in R^n$.

The Centering Parameter (σ)

It balances the movement towards the central path against the movement toward optimal solutions. If $\sigma = 1$, then the updates move towards the center of the feasible region. If $\sigma = 0$, then the update step is in the direction of the optimal solution.

The Duality Gap (μ)

It is the difference between the primal and dual objective functions. Theoretically, these two quantities are equal and so give a result of zero (0) at optimality. In practice however, the algorithm drives the result down to a small amount. This is given by the equation:

$$\mu \equiv \frac{1}{n}(x^T s) = c^T x - b^T y$$

While $\mu \geq \varepsilon$, Newton's method is applied until $\mu \leq \varepsilon$ when the algorithm terminates. ε is a positive fixed number.

The general standard minimum problem and the dual standard maximum problem may be together illustrated as:

Table 3.2; shows standard minimum and dual maximum constraints

	x_1	x_2	$\cdots$	x_n	
y_1	a_{11}	a_{12}	$\cdots$	a_{1n}	$\geq b_1$
y_2	a_{21}	a_{22}	$\cdots$	a_{2n}	$\geq b_2$
.	.	.		.	.
.	.	.		.	.
.	.	.		.	.
y_n	a_{m1}	a_{m2}	$\cdots$	a_{mn}	$\geq b_m$
	$\leq c_1$	$\leq c_2$	$\cdots$	$\leq c_n$	

3.5.8 The Primal-Dual Algorithm

Initialization

1. Choose $\beta, \gamma \in (0,1)$ and $(\varepsilon_P, \varepsilon_D, \varepsilon_G) > 0$.

Choose (x^0, y^0, s^0) such that $(x^0, s^0) > 0$ and $\|X^0 s^0 - \mu_0 e\| \leq \beta\mu_0$

where $\mu_0 = \dfrac{(x^0)^T s^0}{n}$.

2 Set $k = 0$

3. Set $r_p^k = b - Ax^k$, $r_D^k = c - Ak^T y^k - s^k$, $\mu_k = \dfrac{(x^k)^T s^T}{n}$

4. Check the termination. If $\left\| r_P^k \right\| \le \varepsilon_P$, $\left\| r_D^k \right\| \le \varepsilon_D$, $(x^k)^T s^k \le \varepsilon_G$, then terminate.

5. Compute the direction by solving the system

$$\begin{bmatrix} A & 0 & 0 \\ 0 & A^T & I \\ S^k & 0 & A^k \end{bmatrix} \begin{bmatrix} d_x \\ d_y \\ d_s \end{bmatrix} = \begin{bmatrix} r_P^k \\ r_D^k \\ -X^k s^k + \gamma \mu_k e \end{bmatrix}$$

6. Compute the step size

$\alpha = \max\{\alpha' : \left\| X(\alpha)s(\alpha) - \mu(\alpha)e \right\| \le \beta(\alpha), \forall \alpha \in [0, \alpha']\}$, where

$x(\alpha) = x^k + \alpha d_x$, $s(\alpha) = s^k + \alpha d_s$ and $\mu(\alpha) = \dfrac{x^T(\alpha)s(\alpha)}{n}$.

7. Update $x^{k+1} = x^k + \alpha_k d_x$, $y^{k+1} = y^k + \alpha d_y$, $s^{k+1} = s^k d_s$

8. Set $k = k + 1$, and go to step 3.

3.6 SUMMARY

In this chapter, Linear Programming and Simplex method were discussed. The analysis on the Linear Programming and Simplex method also form part of the discussion in this chapter.

In the next chapter, the data collected from the farm will be used to formulate the linear programming model and solve using the Matlab.

CHAPTER FOUR

DATA COLLECTION, ANALYSIS AND IMPLEMENTATION OF MODEL

4.0 Introduction

This study aimed at using the linear programming technique to formulate least cost balanced ration for starter and finisher types of broiler using local feed ingredients. The main goal of the study is to reduce the cost of broiler production in Dormaa-Ahenkro. The feed ingredients used were maize, soya bean, wheat bran, fish meal, concentrate, premix, cotton, Oyster shell, lysine and methionine.

Constructed Linear Programming (LP) models were designed to reflect various feedstuff combinations used in the diet formulation, current market prices, nutrient composition and range of inclusion to obtain a least-cost ration for broilers according to the available feedstuffs in Dormaa Municipality. The objective of the models was to minimize cost of producing one tone (1000kg)of feed after satisfying a set of constraints. The variables in the models were the ingredients while the cost of each ingredient and the nutrient value of each ingredient was the parameter. The variation in the cost is a result of the variation in the nutrient requirements of the birds according to the stage of production. Each stage requires certain level of combined nutrients in the used feedstuffs. This will cause different quantities of feedstuffs to be used in each ration.

Feed formulation is the process of quantifying the amounts of feed ingredients that need to be put together, to form a single uniform mixture (diet) for poultry that supplies all of their nutrient requirements. It is important that returns are maximized through use of adequate diets. Feed formulation is a central operation in poultry production, ensuring that feed ingredients are economically used for optimum growth of chickens. Most large-scale poultry farmers depend on commercial feed mills for their feeds, to obviate the need to do their own formulations or feed preparation. It is therefore essential that formulations are accurate, to ensure a large number of flocks are not adversely affected (Chung et al. 1983).

The problem of least-cost ration formulation in poultry can be effectively managed through using linear programming technique (Olorunfemiet et al., 2006). Patrick and Schaible (1980) defined least cost feeds as the lowest-cost formula that contains all the nutritional elements needed for maximum performance. This study aimed at using the linear programming technique to formulate least cost balanced ration for broilers at different stages of life period using local feed ingredients.

4.1 Source and Data Collection

Data collected for this study were based on raw material (feedstuffs) specification, constrained imposed on the selected raw material and the dietary nutrient requirements in each stage of life of broiler flocks. The main source for these data was the Boris B's farms and Veterinary Services Ghana limited, Nutrient Requirement of Poultry Ninth Revised Edition (2000).

Costs of feedstuffs used in the diet formulation were obtained from the prevailing market prices of feedstuffs in Dormaa municipality through survey. The analysis of feed ingredients and minimum and maximum levels of various feedstuffs used in diet obtained from standard tables and sources.

Feedstuffs used in ration formulation for local poultry farms include maize (x_1), soya bean (x_2), wheat bran (x_3), fish meal (x_4), lysine (x_5), concentrate (x_6), premix (x_7), cotton (x_8), oyster shell (x_9) and methionine (x_{10}).

Cost implications of feedstuffs and nutrient levels of feed ingredients, constraints imposed on the selection of feedstuffs for broiler rations and least-cost formulation restrictions on nutrients and feedstuffs for broiler rations are summarized in the tables below.

Table 4.0 cost implications of feedstuffs and nutrient levels of feed ingredients

Nutrients	cost (**Gh¢**)/kg	crude protein (%)	fat (%)	crude fiber (%)	calcium (%)	phos-phorus (%)	lysine (%)	meth-ionine (%)	ME (k/cal)
(x_1)	0.70	8.8	4.0	2.0	0.1	0.34	0.4	0.18	3432
(x_2)	1.40	48	3.5	6.5	0.2	0.37	3.2	0 .59	2557
(x_3)	2.00	13	0	5.1	0.05	1.20	0.5	0.42	3153
(x_4)	1.80	60	4.5	1.0	6.5	3.5	4.5	1.8	2950
(x_5)	7.00	95	0	0	0	0	100	0	0
(x_6)	2.60	12	0.25	4.75	1.50	1.50	0.2	0.15	1260
(x_7)	3.00	0	0	0	0	0	0	0	0
(x_8)	1.40	39.6	0	0	0.15	0.48	62.8	71.9	2350
(x_9)	0.24	0	0	0	38	0	0	0	0
(x_{10})	5.00	60	0	0	0	0	0	10	0

Table 4.1 constraint imposed on the selection of feedstuffs for starter broiler rations

Nutrients	maximum level	minimum level
Crude protein (%)	-	23
ME(Kcal/kg)	3200	2800
Calcium (%)	15	10
Phosphorus (%)	-	45
Fat (%)	50	-
Crude fiber (%)	50	-
Lysine (%)	-	11
Methionine (%)	-	5

Table 4.2 constraint imposed on the selection of feedstuffs for finisher broiler rations

Nutrients	maximum level	minimum level
Crude protein (%)	-	18
ME(Kcal/kg)	3400	3200
Calcium (%)	25	10
Phosphorus (%)	-	55
Fat (%)	60	-
Crude fiber (%)	50	-
Lysine (%)	-	11
Methionine (%)	-	5

Table 4.3 Least-cost formulation restrictions on nutrients and feedstuffs for broiler rations

Item	starter stage	finisher stage
Weight (kg)	1000	1000
Crude protein (%)	≤ 23	≤18
ME(Kcal/kg)	≤ 2800	≤3200
Calcium (%)	≥15	≤ 10
Phosphorus (%)	≤45	≤45
Fat (%)	≥50	≥60
Crude fiber	≥50	≥50
Lysine (%)	≤11	≤11
Methionine (%)	≤5	≤5

4.2 Formulation of LP Model for Feed Mixed

The objective function of the proposed model is formulated as;

Minimize$Z = \sum C_{ij} X_j$

Where;

Z = Total cost of the ration

C_j = Ingredient cost, $j = 1,2,3, \dots, m$

X_i = Ingredient quantity, $i = 1,2,3, \dots, n$

Subject to

$x_1 + x_2 + x_3 + \cdots + x_8 = b_1$

$a_{11}x_1 + a_{12}x_2 + \cdots + a_{18}x_8 \leq b_2$

$a_{21}x_1 + a_{22}x_2 + \cdots + a_{28}x_8 \leq b_3$

$a_{31}x_1 + a_{32}x_2 + \cdots + a_{38}x_8 \leq b_4$

$a_{41}x_1 + a_{42}x_2 + \cdots + a_{48}x_8 \leq b_5$

$a_{51}x_1 + a_{52}x_2 + \cdots + a_{58}x_8 \leq b_6$

$a_{61}x_1 + a_{62}x_2 + \cdots + a_{68}x_8 \leq b_7$

$a_{71}x_1 + a_{72}x_2 + \cdots + a_{78}x_8 \leq b_8$

$a_{81}x_1 + a_{82}x_2 + \cdots + a_{88}x_8 \leq b_9$

$a_{91}x_1 + a_{92}x_2 + \cdots + a_{98}x_8 \leq b_{10}$

$a_{101}x_1 + a_{102}x_2 + \cdots + a_{108}x_8 \leq b_{11}$

$x_i \geq 0, i = 1,2,3, \dots, n$

where:

a_i = Technical coefficients of nutrient components in feedstuffs

b_i = Constraints of the ration.

4.3 Implementation of Proposed LP Model

The model is implemented in two ways:

(i) LP for least cost starter ration

(ii) LP for least cost finisher ration

The LP model for the least cost starter ration

Substituting the various ingredients in the tables 4.0 and 4.3 into the model, we have

$$\min(Z) = 0.7x_1 + 1.4x_2 + 2x_3 + 1.8x_4 + 7x_5 + 2.6x_6 + 3x_7 + 1.4x_8 + 0.24x_9 + 5x_{10}$$

Subject to :

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 \leq 1000$

$8.8x_1 + 48x_2 + 13x_3 + 60x_4 + 95x_5 + 12x_6 + 39.6x_8 \leq 23$

$4x_1 + 3.5x_2 + 4.5x_3 + 0.25x_6 \leq 5$

$2x_1 + 6.5x_2 + 5.1x_3 + 1x_4 + 4.75x_6 \leq 5$

$0.1x_1 + 0.2x_2 + 0.05x_3 + 6.5x_4 + 1.5x_6 + 0.15x_8 + 38x_9 \leq 1.5$

$0.34x_1 + 0.37x_2 + 1.2x_3 + 3.5x_4 + 1.5x_6 + 0.48x_8 \leq 0.45$

$0.40x_1 + 3.2x_2 + 0.5x_3 + 4.5x_4 + 100x_5 + 0.2x_6 + 62.8x_8 \leq 1.51$

$0.18x_1 + 0.59x_2 + 0.42x_3 + 1.8x_4 + 0.15x_6 + 71.9x_8 + 100x_{10} \leq 0.5$

$3432\, x_1 + 2557x_2 + 3153x_3 + 2950x_4 + 1260x_6 + 2350x_8 \leq 2800$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10} \geq 0$

The LP Model for the Least Cost Finisher Ration

Substituting the various ingredients in the tables 4.0 and 4.3 into the model, we have

$\min(Z) = 0.7x_1 + 1.4x_2 + 2x_3 + 1.8x_4 + 7x_5 + 2.6x_6 + 3x_7 + 1.4x_8 + 0.24x_9 + 5x_{10}$

Subject to :

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 \leq 1000$

$8.8x_1 + 48x_2 + 13x_3 + 60x_4 + 95x_5 + 12x_6 + 39.6x_8 \leq 21$

$4x_1 + 3.5x_2 + 4.5x_3 + 0.25x_6 \leq 6$

$2x_1 + 6.5x_2 + 5.1x_3 + 1x_4 + 4.75x_6 \leq 5$

$0.1x_1 + 0.2x_2 + 0.05x_3 + 6.5x_4 + 1.5x_6 + 0.15x_8 + 38x_9 \leq 1.5$

$0.34x_1 + 0.37x_2 + 1.2x_3 + 3.5x_4 + 1.5x_6 + 0.48x_8 \leq 0.45$

$0.40x_1 + 3.2x_2 + 0.5x_3 + 4.5x_4 + 100x_5 + 0.2x_6 + 62.8x_8 \leq 1.51$

$0.18x_1 + 0.59x_2 + 0.42x_3 + 1.8x_4 + 0.15x_6 + 71.9x_8 + 100x_{10} \leq 0.5$

$3432\, x_1 + 2557x_2 + 3153x_3 + 2950x_4 + 1260x_6 + 2350x_8 \leq 3200$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10} \geq 0$

4.4.0 Solution of LP Model for the Least Cost Starter Ration

The resulting model for the case study farm was solved using matlab. The resulting optimal solution was compared with the existing practice on the farm as summarized in table 4.6.

Matlab package of syntax linprog as shown below was used.

f = [-0.70 -1.40 -0.48 -1.80 -7.00 -2.60 -3.00 -1.00 -0.24 -5.00]

$$
A = \begin{bmatrix}
8.8 & 48 & 13 & 60 & 95 & 12 & 0 & 39.6 & 0 & 60 \\
4.0 & 3.5 & 0 & 4.5 & 0 & 0.25 & 0 & 0 & 0 & 0 \\
2.0 & 6.5 & 5.1 & 1.0 & 0 & 4.75 & 0 & 0 & 0 & 0 \\
0.1 & 0.2 & 0.05 & 6.5 & 0 & 1.5 & 0 & 0.15 & 38 & 0 \\
0.34 & 0.37 & 1.2 & 3.5 & 0 & 1.5 & 0 & 0.48 & 0 & 0 \\
0.4 & 3.2 & 0.5 & 4.5 & 100 & 0.2 & 0 & 62.8 & 0 & 0 \\
0.18 & 0.59 & 0.42 & 1.8 & 0 & 0.15 & 0 & 71.9 & 0 & 100 \\
3432 & 2557 & 153 & 2950 & 0 & 1260 & 0 & 2350 & 0 & 0
\end{bmatrix}
$$

B = [23 5.0 5.0 1.5 0.45 1.51 0.5 2800]

lb = zeros (10,1)

ub = ones (10,1)

Beq = [ ]

Aeq = [ ]

[x, fval, exitflag, output, lambda] = linprog (f , A, B, Aeq, Beq, lb, ub, [ ], [ ])

Table 4.4 Results and Discussion of the Least Cost Starter Ration

Decision Variable	Solution Variable	Unit Cost	Total Cost	Reduced Cost
Maize (x_1)	517	0.70	361.90	-11.90
Soya bean(x_2)	356.7	1.40	499.38	-219.38
Wheat bran (x_3)	0	2.00	0.00	146.00
Fish meal (x_4)	0	1.80	0.00	144.00
Lysine(x_5)	1.40	7.00	9.80	-2.80
Concentrate (x_6)	90.0	2.60	234.00	-52.00
Premix (x_7)	1.00	3.00	3.00	0.00
Cotton (x_8)	0	1.40	0.00	35.00
Oyster shell(x_9)	32.7	0.24	7.85	4.15
Methionine (x_{10})	1.8	5.00	9.00	-4.00
Total Reduction Cost				39.07

The objective of the study was to minimize cost of producing one tone of feed after satisfying a set of constraint without compromising the nutritional value of the feed. From the solution of the model by a computerized solution, the quantity of wheat bran, fish meal and cotton were reduced to zero (0 kg) since almost the nutritional value they offer can also be found in the other ingredients (constraint), for that matter, there is no economic value in adding those ingredients to the feed. Whiles the quantity of maize, soya bean, lysine, concentrate and methionine were increased in other to supplement for the nutritional value that the wheat bran, fish meal and cotton would have offer. However, the quantity of oyster shell was reduced and the quantity of premix was maintained in other to balance the nutritional level of the feed. This model reduces the feed cost by almost Gh¢ 39.00.

4.4.1 Solution of LP Model for the Least Cost Finisher Ration

The resulting model for the case study farm was solved using matlab. The resulting optimal solution was compared with the existing practice on the farm as summarized in table 4.7.

Matlab package of syntax linprog as shown below was used.

f = [-0.70 -1.40 -0.48 -1.80 -7.00 -2.60 -3.00 -1.00 -0.24 -5.00]

$$A=\begin{bmatrix} 8.8 & 48 & 13 & 60 & 95 & 12 & 0 & 39.6 & 0 & 60 \\ 4.0 & 3.5 & 0 & 4.5 & 0 & 0.25 & 0 & 0 & 0 & 0 \\ 2.0 & 6.5 & 5.1 & 1.0 & 0 & 4.75 & 0 & 0 & 0 & 0 \\ 0.1 & 0.2 & 0.05 & 6.5 & 0 & 1.5 & 0 & 0.15 & 38 & 0 \\ 0.34 & 0.37 & 1.2 & 3.5 & 0 & 1.5 & 0 & 0.48 & 0 & 0 \\ 0.4 & 3.2 & 0.5 & 4.5 & 100 & 0.2 & 0 & 62.8 & 0 & 0 \\ 0.18 & 0.59 & 0.42 & 1.8 & 0 & 0.15 & 0 & 71.9 & 0 & 100 \\ 3432 & 2557 & 153 & 2950 & 0 & 1260 & 0 & 2350 & 0 & 0 \end{bmatrix}$$

B = [19.5 3.13 3.89 2.11 0.52 0.58 0.53 3232]

lb = zeros (10,1)

ub = ones (10,1)

Beq = [ ]

Aeq = [ ]

[x, fval, exitflag, output, lambda] = linprog (f , A, B, Aeq, Beq, lb, ub, [ ], [ ])

Table 4.5 Results and Discussion of the least Cost Finisher Ration

Decision Variable	Solution Variable	Unit Cost	Total Cost	Reduced Cost
Maize (x_1)	696.4	0.70	487.48	-46.48
Soya bean (x_2)	84.9	1.40	118.86	91.14
Wheat bran (x_3)	0	2.00	0.00	60.00
Fish meal (x_4)	0	1.80	0.00	45.00
Lysine (x_5)	0	7.00	0.00	17.50
Concentrate (x_6)	168.7	2.60	438.62	-139.62
Premix (x_7)	1.00	3.00	3.00	0.00
Cotton (x_8)	0	1.40	0.00	5.60
Oyster shell (x_9)	46.7	0.24	11.21	-1.61
Methionine (x_{10})	3.3	5.00	16.50	-0.50
Total Reduction Cost				31.03

The objective of the study was to minimize cost of producing one tone of feed after satisfying a set of constraint without compromising the nutritional value of the feed. From the solution of the model by a computerized solution, the quantity of wheat bran, fish meal, lysine and cotton were reduced to zero (0 kg) since almost the nutritional value they offer can also be found in the other ingredients (constraint), for that matter, there is no economic value in adding those ingredients to the feed. Whiles the quantity of maize, concentrate, oyster shell and methionine were increased in other to supplement for the nutritional value that the wheat bran, fish meal, lysine and cotton would have offer. However, the quantity of soya bean was reduced and the quantity of premix was maintained in other to balance the nutritional level of the feed. This model reduces the feed cost by almost Gh¢ 31.03.

Table 4.6 Least Cost Starter Ration versus Existing Practice

		Exiting practice		Proposed solution	
Ingredients (x_j)	cost(**Gh¢**)/kg	value(kg)	cost (Gh¢)	value (kg)	cost (Gh¢)
Maize	0.70	500	350.00	517	361.90
Soya bean	1.40	200	280.00	356.7	499.38
Wheat bran	2.00	73	146.00	0	0.00
Fish meal	1.8	80	144.00	0	0.00
Lysine	7.00	1	7.00	1.4	9.80
Concentrate	2.60	70	182.00	90	234.00
Premix	3.00	1	3.00	1	3.00
Cotton	1.40	25	35.00	0	0.00
Oyster shell	0.24	50	12.00	32.7	7.85
Methionine	5.00	1	5.00	1.8	9.00
Objective function value		1001	1164.00	1000.6	1124.93

The cost of producing broiler starter feed is Gh¢1164.00 using the existing practice of the farm compared with the Gh¢1124.93 if feed formulation is based on the proposed mathematical model. This is a substantial savings of about 3.36%. Obviously feed formulation is more cost effective when based on valid mathematical programming.

Table 4.7 Least Cost Finisher Ration versus Existing Practice

		Exiting practice		Proposed solution	
Ingredients (x_j)	cost(**Gh¢**)/kg	value(kg)	cost (Gh¢)	value (kg)	cost (Gh**¢**)
Maize	0.70	630	441.00	696.4	487.48
Soya bean	1.40	150	210.00	84.9	118.86
Wheat bran	2.00	30	60.00	0	0.00
Fish meal	1.8	25	45.00	0	0.00
Lysine	7.00	2.5	17.50	0	0.00
Concentrate	2.60	115	299.00	168.7	438.62
Premix	3.00	1	3.00	1	3.00
Cotton	1.40	4	5.60	0	0.00
Oyster shell	0.24	40	9.60	46.7	11.21
Methionine	5.00	3.2	16.00	3.3	16.50
Objective function value		1000.7	1106.70	1001	1075.67

The cost of producing broiler finisher feed is Gh¢ 1106.70 using the existing practice of the farm compared with the Gh¢ 1075.67 if feed formulation is based on the proposed mathematical model. This is a substantial savings of about 2.80%. Obviously feed formulation is more cost effective when based on valid mathematical programming.

4.5 Summary

In this chapter existing practice for both starter and finisher ration were compared with the mathematical model for both starter and finisher ration to see which one is more cost effective.

In the next chapter, we shall put forward relevant conclusion and recommendation made from this study.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter presents the conclusions drawn from the study and makes some recommendations to help the poultry industry in order to optimize the profit margin.

5.1 Summary

This study was on the economic use of the local feedstuffs to formulate least cost rations for broilers using Linear Programming (LP) technique to investigate, analyze and indicate how best the available local ingredients can be combined effectively and efficiently to formulate least-cost ration for broilers. Mathematical models were constructed by taking into consideration nutrient requirements of the broilers, nutrient composition of the available ingredient and any other restriction factor of the available ingredients for the formulation. The result of this study showed that the least cost ration for starter broiler produced by linear programming model consists of 51.7% maize, 35.67% soya bean, 0.14% lysine, 9% concentrate, 0.1% premix, 3.27% oyster shell and 0.18% methoinine. For the finisher ration, the results showed that the ration consists of 69.64% maize, 8.49% soya bean, 16.87% concentrate, 0.1% premix, 4.67% oyster shell, 0.33% methoinine.

The poultry industry has a significant effect on national economy; it is a popular industry for the small holders with tremendous contribution to GDP and employment creation. Poultry feed cost represents over sixty (60) percent of the total cost of poultry production; consequently efficient feed formulation practice is required for a sustainable poultry industry. Many Ghanaian poultry farmers, however, employ inefficient methods like rule of thumb, experiences, and intuition to handle feed formulation problem. The aim of this study was to develop an optimization feed formulation model, using locally available feed ingredients for the Ghanaian poultry industry. Relevant literature was consulted to gather information on the practices prevalent in the industry, nutrient contents and availability of feed ingredients and their prevalent market prices. The decision variables, objective function and problem constraints were defined and a mathematical model of the feed formulation problem was developed and parameterized using data from a typical commercial farm. Model solution and post-optimality analysis results were obtained and compared with existing practice of the case study farm. Ten (10) decision variables and eight (8) constraints were identified. The optimal solution of the linear programming model for the least cost starter ration gives 11% reduction in broiler starter feed formulation compared to the existing method on the farm whiles the optimal solution of the linear programming model for the least cost finisher ration gives 3% reduction in broiler finisher feed formulation compared to the existing method on the farm.

The model will be very useful in poultry farm management in Ghana.

5.2 Discussions and Conclusion

The results of least cost diet formulation produced by linear programming model showed that the starter ration consists of 51.7% maize, 35.67% soya bean, 0.14% lysine, 9% concentrate, 0.1% premix, 3.27% oyster shell and 0.18% methionine. This ration meets all the nutritional requirements needed for starter broiler. The cost of the ration is around Gh¢ 1124.93 per ton. This model saves about Gh¢ 39.00 per ton compared to the basic ration.

For the finisher ration the results showed that the ration consists of 69.64% maize, 8.49% soya bean, 16.87% concentrate, 0.1% premix, 4.67% oyster shell, 0.33% methoinine. This ration meets all the nutritional requirements needed for finisher broiler. The cost of the ration is around Gh¢ 1106.70 per ton. This model saves about Gh¢ 31.03 per ton compared to the basic ration.

5.2 Recommendations

Controlling feed costs is critical to the sustainability of the Ghanaian poultry Industry. This study has demonstrated how the application of a linear programming approach to feed formulation will lead to higher productivity in this sector as opposed to the use of relatively inefficient methods such as the trial and error method. Approximately three percent (3%) reduction in costs were made in both the starter and finisher ration with the implementation of the new method.

This model was based on an existing practice in the Dormaa Municipality taking into account the locally available feed ingredients and improving on the existing practice prevalent in the poultry industry in the municipality.

The general model can be extended to tackle other types of feed formulation, although this study has focused on broiler ration, the model can easily be adapted to suit other types of rations.

From the conclusion we realized that using scientific methods to produce feed helps the poultry farmers to increase their profits. Hence we recommend the poultry industry should adapt this model in their feed production.

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